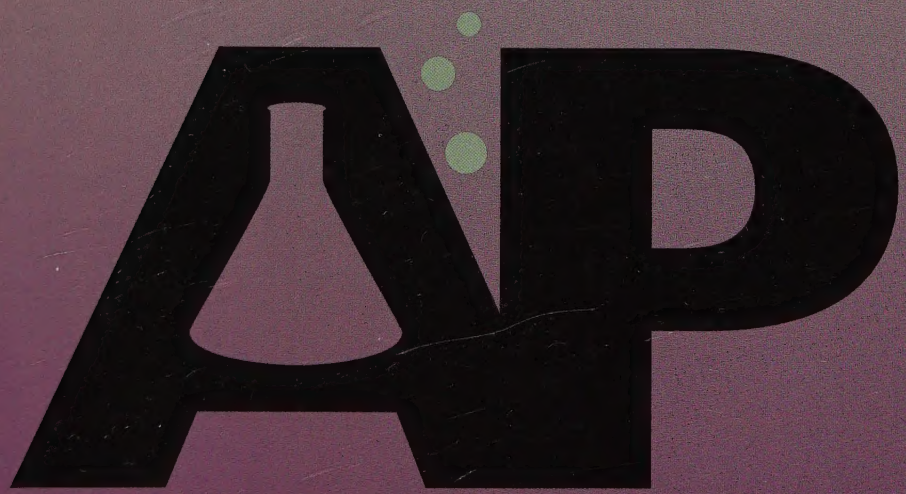
STUDENT'S SOLUTIONS MANUAL

MULTIPLE-CHOICE & CONSTRUCTED-RESPONSE QUESTIONS IN PREPARATION FOR THE AP CHEMISTRY EXAMINATION



CHEMISTRY

DAVID HOSTAGE
PATSY MUELLER
ARDEN ZIPP

• SIXTH EDITION •

STUDENT'S SOLUTIONS MANUAL

TO ACCOMPANY

MULTIPLE-CHOICE & CONSTRUCTED-RESPONSE QUESTIONS IN PREPARATION FOR THE AP CHEMISTRY EXAMINATION

(SIXTH EDITION)

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PREFACE

The academic year 2013–2014 marks the beginning of a new curriculum for AP Chemistry and the examinations starting with 2014 will be in a new format to evaluate student understanding of that new curriculum. The new Curriculum Framework divides chemistry into six Big Ideas, each divided into Enduring Understandings. The Enduring Understandings are broken into Essential Knowledge (what you, the student, should know) and Science Practices (what you, the student, can do with that knowledge). Learning Objectives link the Enduring Understandings and Science Practices. Each question is coded to allow you, the student, to relate it to the new Curriculum Framework.

This Student's Solutions Manual will give you answers to the hundreds of multiple-choice questions in the accompanying review book, each written in the format of the new exam. In most cases there are also detailed explanations of the incorrect answers offered for each question. Solutions are also offered for each constructed-response question, all structured to reflect the latest style of the new exam format.

The authors of this Student's Solutions Manual have spent thousands of hours in planning, collaborating, writing, and reviewing since the changes to the AP Chemistry curriculum and examination were announced in late April 2013. We wish to thank a major group of contributors to the project: students. Although they may not have been aware of it, our students over the years have challenged us as much as we have challenged them. The freshness and originality of their thinking in our own classrooms has prompted us to look frequently at chemistry in a new light. All students who have written past AP Chemistry exams have caused us, through each response to each question, to reflect upon our understanding of their understanding of the chemistry as we evaluated their work. To all of you students, we offer our thanks.

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INTRODUCTION

The AP Chemistry program has been redesigned recently. There are new Frameworks to describe the curriculum and the examination itself has been organized into a new format. How do these changes affect you, the student? Let us look first at the structure of the curriculum redesign; then we will show you a simple code to help you to organize your thoughts about each question in the review and problem book. Then we will tell you how the multiple-choice and constructed-response questions in the book, along with the solutions found in this Student's Solutions Manual, will help you to prepare for the new format of the AP Chemistry examination.

The redesigned AP Chemistry course is organized around six Big Ideas, which encompass virtually all of chemistry. These are:

Big Idea 1: The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangement of atoms. These atoms retain their identity in chemical reactions.

Big Idea 2: Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Big Idea 6: Any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations.

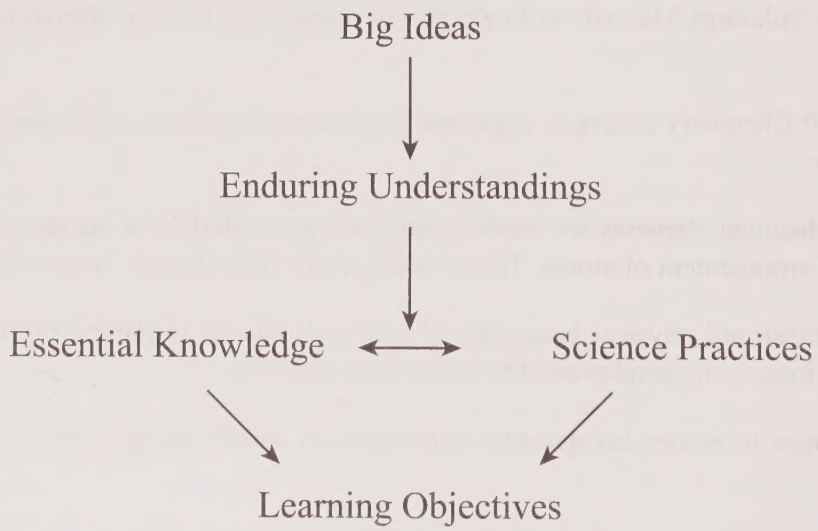
Each Big Idea is divided into a series of statements (referred to as Enduring Understandings), each of which addresses a particular aspect of it Big Idea. For example, the first Enduring Understanding under Big Idea 1 is: "All matter is made of atoms. There are a limited number of types of atoms; these are the elements."

Enduring Understandings, in turn, are subdivided into statements of Essential Knowledge, which summarize the material required of students and include under them the details of this material. For example, Big Idea 1 comprises five Enduring Understandings, each of which includes two or three Essential Knowledge statements for a total of twelve such statements. The Enduring Understandings are also connected to seven Science Practices, each of which specifies a particular skill that students are expected to display on exams.

Each of the Essential Knowledge statements and the supporting material in them culminates in one or more Learning Objectives. An example of a Learning Objective that should be familiar to everyone who has taken a chemistry course is the following (LO 1.2): "The student is able to select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures." The Science Practice that accompanies this LO is SP 2.2 that states: The student can apply mathematical routines to quantities that describe natural phenomena."

In all, there are 117 Learning Objectives. Theoretically, a student could prepare for the AP exam by ensuring that he/she could respond successfully to each of these Learning Objectives because every question that is used on the exam must be linked to a specific Learning Objective and Science Practice.

A schematic diagram of the Redesign Project and the relationship among the various aspects described above is given below.



You can find further descriptions of each of these aspects of the redesign at http://media.collegeboard.com/digitalServices/pdf/ap/11_3461_AP_CF_Chemistry_WEB_110930.pdf.

The Classification Code and Student Learning.

How can you, the student, use the code that accompanies each question in the Student's Solutions Manual to link that question to the Curriculum Framework? Let us look at an example:

[LO 4.1, SP 4.2, 5.1]

This code refers specifically to a Big Idea, a Learning Objective, and two Science Practices.

The first number following *LO* indicates the Big Idea, in this case Big Idea 4 (kinetics), previously stated as "Rates of chemical reactions are determined by details of the molecular collisions."

The second number, following the Big Idea number and preceded by a decimal point, refers to the Learning Objective. In this example, *LO 4.1* refers to Big Idea 4 Learning Objective 1. This links to *LO 4.1*, "The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction."

The numbers following *SP* indicate the specific Science Practice, in this example 4.2 and 5.1. Science Practice 4 states "The student can plan and implement data collection strategies in relation to a particular scientific question. [Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction, and/or archived data.]" The specific reference is to Science Practice 4.1, which states " The student can justify the selection of the kind of data needed to answer a particular scientific question." The second reference is to Science Practice 5, which states "The student can perform data analysis and evaluation of evidence." and specifically to Science practice 5.1, which says "The student can analyze data to identify patterns or relationships."

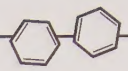
Why should you, the student, be aware of this background information and the shorthand code? Because the exam will include questions that link specifically to the Learning Objectives and Science Practices! Plan your review to include as many *LO*s and *SP*s as possible. Using this Student's Solutions Manual and the recommended link will allow you to do just that.

The New Exam Format

The new AP Chemistry examination is a comprehensive evaluation of your mastery of most of the topics of a first year college chemistry course. The examination includes multiple-choice and constructed-response sections, each weighed as 50% of the score total and each allowed ninety minutes.

The multiple-choice section will include 60 questions, each with four answer choices. Since there is no penalty for guessing at an answer (there is no deduction of points for doing so), be sure to mark an answer for each multiple-choice question. About half of the multiple-choice questions will be found in item sets, where several questions are linked to one set of data, graph, diagram, or other information source. Use of a calculator is NOT permitted in this section but you will have access to a Periodic Table and List of Equations.

The constructed-response section will include a total of seven questions, each with several parts. Three of the questions will be longer and more complicated while four will be shorter. Most questions will ask about more than one Big Idea of chemistry. You will be expected to show your mastery of the concepts and skills as keyed to the Learning Objectives and Science Practices. You will definitely need to review your laboratory



work, because one or more of the constructed-response questions will link to laboratory design, especially the inquiry-based lab work new to the curriculum as well as your ability to engage in data analysis.

Both the new constructed-response and multiple-choice questions will also assess your ability to engage in data analysis, especially working with data tables and graphical information, and will often ask you to construct a diagram, assessing your conceptual understanding of the material. The question might ask for a PES energy diagram, a reaction progress (kinetics) potential energy diagram, or ask you to create a diagram of two beakers illustrating the difference between the contents of a 1 *M* HCl solution vs a 1 *M* $HC_2H_3O_2$ solution, among many other possibilities.

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CHAPTER 1

ATOMIC STRUCTURE

1. Electromagnetic radiation frequencies increase in the order; radio waves, infrared, visible, ultraviolet, x-rays, gamma rays. The highest frequency corresponds to the shortest wavelength. By either measure the highest frequency is seen for x-rays.

   The correct answer is (D).

   [LO 1.6 SP 5.1]

2. The wavelength of electromagnetic radiation increases in the order; gamma rays, x-rays, ultraviolet, visible, infrared, radio waves. The longest wavelength of the choices given is infrared.

   The correct answer is (A).

   [LO 1.6 SP 5.1]

3. Since $E = h\nu$, a photon with the highest energy would correspond to radiation with the highest frequency. Of the choices given this is x-ray. (See answer to q. 1)

   The correct answer is (D).

   [LO 1.6 SP 5.1]

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4. Fireworks displays are characterized by the appearance of light to which the human eye responds. This is mostly visible radiation.

   The correct answer is (C).

   [LO 1.6 SP 5.1]

5. With $c = \nu\lambda$ and $E = h\nu$, $E = hc/\lambda$. Therefore, $E = h(3.00 \times 10^{8}\text{m})\ /300 \times 10^{-9}\text{m}$ and $E = 1.00 \times 10^{15}\text{h}$.

   The correct answer is (B).

   [LO 1.6 SP 5.1]

6. As a member of group I sodium, choice (A), loses one electron to form an ion with a +1 charge. Magnesium in Group II, choice (B), forms +2 ions. The chalcogen/Group 16 elements gain two electrons to form ions with –2 charges. Chlorine (a halogen), choice D, gains one electron to form an ion with a -1 charge.

   The correct answer is (C).

   NOTE: In constructed-reponse questions that deal with periodic properties, only partial credit may be awarded for answers that are based on trends in the Periodic Table. In contrast, answers that rely on the chemical principles that are responsible for those trends are likely to receive more credit.

   [LO 1.9 SP 6.4]

7. Reactivity of metals increases to the left and down the PT. The element that is lowest and farthest to the left on the Periodic Table will be the most reactive. Sodium, choice (A), would be more reactive than magnesium, choice (B), because it is to the left of magnesium on the PT. However, potassium, choice (C), lies below sodium so potassium will be more reactive than sodium and also more reactive than calcium, choice (D), which lies to the right of potassium. The element that will react most vigorously is potassium.

   The correct answer is (C).

   [LO 1.10 SP 6.1]

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8. Atomic size increases down and to the left on the PT. The first trend is due to valence electrons occupying higher principal energy levels that are farther from the nucleus. The second trend is due to the increase in Z_{eff} toward the right within any given period as the protons added to the nucleus are only partially screened. Phosphorus, choice (C), and sulfur, choice (D), are larger than nitrogen, choice (A), and oxygen, choice (B), because they are in a higher period with valence electrons in a higher principal level. Phosphorus is larger than sulfur because the Z_{eff} of sulfur is greater than that of phosphorus.

   The correct answer is (C).

   [LO 1.9 SP 6.4]

9. The IE increases by a factor of 9 between the first and second electrons, which is consistent with the second electron being removed from an inner principal level. For each of the subsequent pairs of electrons (electrons II and III, electrons III and IV, electrons IV and V) the IE increases are each about 50%. These changes are consistent with the changes within a period. Therefore, only the first electron is a valence electron.

   The correct answer is (A).

   [LO 1.5 SP 6.2]

10. Because the question refers to a specific atom the nucleus is the same, with a constant charge and size so choices (A) and (B) cannot be correct. As each electron is removed, the charge on the ions formed increases rather than decreasing so option (D) cannot be correct. With the removal of each electron, fewer are left to repel those that remain, thereby increasing their attraction between the nucleus and the energy needed to remove them.

    The correct answer is (C).

    [LO 1.7 SP 5.1]

11. Ionization energies increase toward the top and right of the Periodic Table because the outermost electrons are in lower principal energy levels (and therefore are closer to the nucleus) with greater attractions to the nucleus near the top of the Periodic Table. The Z_{eff} values increase toward the right in any period where subsequent electrons enter the same principal energy level and are subject to higher attractions due to inefficient screening. Li, choice(A), and Be, choice (B) will have higher ionization energies than the elements below them in their respective families; Na, choice (C), and Mg, choice (D). Further, the Group II elements Be, choice (B) and Mg, choice (D), have higher IEs than the Group I elements to their left. Of the elements given, Be has the highest IE.

    The correct answer is (B).

    [LO 1.9 SP 6.4]

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12. The sublevels fill as 1s < 2s < 2p and one electron enters each of the three 2p orbitals before an electron pairs with one in an orbital. Choice (A) is not correct because the third 2p orbital is unoccupied. Choice (B) is not correct because only one 2p orbital (not three) is represented. Option (C) is incorrect because it assigns two electrons to a 1p orbital which does not exist. Choice (D) assigns two electrons to the 1s, 2s and one of the 2p orbitals with one electron in each of the other 2p orbitals.

    The correct answer is (D).

    [LO 1.5 SP 6.2]

13. According to the Coulomb's Law equation ($F = q_1q_2/r^2$), if the distance is doubled, r^2 equals four and the force, which is inversely related to r^2, is one-quarter as strong. Answer (B) would be correct if the distance were not squared while (C) could be correct if the force were directly dependent on the distance raised to the first power and (D) would be correct if the force were directly dependent on r^2.

    The correct answer is (A).

    [LO 1.7 SP 5.1]

14. The mass of the major isotope is 69.0, choice (A), but the average atomic mass must be higher than that, because of the presence of the second isotope with atomic mass 71.0. The isotopes of mass 69 and 71 are present in the approximate ratio of 3/2. If this ratio were 1/1 the average atomic mass would be 70.0, option (C). If the isotope with mass of 71.0 were more abundant than the isotope with mass 69.0, the average mass would be between 70.0 and 71.0, choice (D), but the greater abundance of isotope 69 makes the average atomic mass lower, i.e. between 69.0 and 70.0.

    The correct answer is (B).

    [LO 1.14 SP 1.4, 1.5]

15. IR radiation can cause atoms in a molecule to vibrate if the vibration is accompanied by a change in the dipole moment of the molecule. Once the frequency of the vibration (ν) has been determined, its energy can be calculated from $E = h\nu$.

    The correct answer is (A).

    [LO 1.15 SP 4.1]

16. UV-visible photons excite electrons in a molecule to higher energy levels.

    The correct answer is (D).

    [LO 1.15 SP 4.1]

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17. Photoelectron spectroscopy (using x-rays → X-PES) can liberate core electrons from an atom. The energies with which the electrons are held in an atom can be found from the differences between the energies of the ejected electrons and those of the incident x-rays.

    The correct answer is (C).

    [LO 1.15 SP 4.1]

18. An absorbance of 0.15 corresponds to a molarity of 0.025 *M* in the 20.0 mL solution. Choice (A) would be correct if, and only if, the concentration in that solution had been sought. Choice (B) would be correct if the measured solution had resulted from a 1:2 dilution. For the 1:10 dilution specified in the question the concentration is 0.25 *M* in the 2.00 mL solution (C). Choice (D) would be correct if the measured solution had been diluted 1:20.

    The correct answer is (C).

    [LO 1.16 SP 4.2]

19. Choice (A), mol/L, represents the units for the x-axis. Choice (B) is the reciprocal of choice (A). Option (C) represents the units of the x-axis multiplied by cm but the slope of the line is $\Delta y/\Delta x$ or $1/M$·cm. This is L/mol·cm.

    The correct answer is (D).

    [LO 1.16 SP 4.2]

20. From the formulas of LiF and Li_3N, the charge on nitride must be –3. Option (A) would require that Mg would be +3 (which does not occur) if N were –3, or that N would be –2 (which never occurs) for Mg^{+2}. Mg^{+2}, choice (B), would require the presence of nonexistent N^{-1}. Choice (C) would require the nonexistent Mg^{+1} for N^{3}. Because the Mg ion has a +2 charge (from MgF_2), the formula for magnesium nitride is Mg_3N_2.

    The correct answer is (D).

    [LO 1.11 SP 5.1]

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21. The mass of an atom, choice (A), has little or no effect on its spectrum, and because isotopes mainly affect the atomic mass, choice (B), the number of them will have a minimal effect on the spectrum. The greater attraction between the electrons and the +3 nucleus of the Li atom, choice (C), would cause a shift of any spectral lines to higher energies, but would not change the number of lines. However, the presence of three electrons in the Li atom leads to the possibility of electron transitions due to energy difference between the s and p sublevels in each n level, choice (D). This creates more transition possibilities than in the H atom), where the only spectral lines are caused by the transitions of the single electron from n to n.

    The correct answer is (D).

    [LO 1.12 SP 6.3]

22. Ionization energies increase toward the right side of the Periodic Table, then drop at the beginning of the next period. The highest IE belongs to a noble gas. Because choices (A) and (B) have values that are lower than choice (C) they cannot belong to a noble gas. Choice (D) with the lowest IE must correspond to an atom with a single electron in a new energy level, which leaves choice (C) with the highest IE.

    The correct answer is (C).

    [LO 1.6 SP 5.1]

23. As stated in the answer to question 22, IEs decrease substantially between the completion of one principal shell and the beginning of another. Because the highest IE corresponds to a noble gas (see answer to q. 22.), element IV (with a low IE) must be an alkali metal.

    The correct answer is (D).

    [LO 1.6 SP 5.1]

24. As stated above, IEs increase across the Periodic Table. The highest IE corresponds to the noble gas at the end of the PT, because the number of electrons and protons increase, but the electrons screen one another inefficiently, leading to greater attractions. The second highest IE in any period belongs to a halogen. This is found for element II, for which the IE is 1681 kJ/mol, choice (B).

    The correct answer is (B).

    [LO 1.6 SP 5.1]

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25. The atomic number, choice (A), which corresponds to the number of protons in the nucleus, certainly increases from left to right across the period. The effective nuclear charge (equal to the number of protons in nucleus minus the screening core electrons), choice (B), increases as does the number of valence electrons, choice (C). For any given period, the number of core electrons is constant.

    The correct answer is (D).

    [LO 1.9 SP 6.4]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) During the late 1800s, before the revolution in physics that occurred at that time, atoms were considered to be solid indivisible particles as suggested by John Dalton.

   (b) Among the experiments that contributed to changes in the atomic model were the following: Gases subjected to high voltages released negative (cathode) rays. This showed that atoms contained smaller entities and were not indivisible.
   OR
   A piece of gold foil was bombarded with alpha particles that mostly went through, although some were deflected, with a few being deflected backwards. This showed that atoms were mostly empty space with most of its mass concentrated in a small nucleus.
   OR
   Some elements (e.g. U) were radioactive, forming other elements. This showed that atoms were not immutable.

   (c) Atoms consist of a massive, positive nucleus surrounded by negative electrons in certain energy levels. Not all atoms of an element are identical (isotopes).

   [LO 1.13 SP 5.3]

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2. (a) A volumetric flask, several volumetric pipets or a measuring pipet, standard solution

   (b) A minimum of three solutions should be prepared so a standard curve can be drawn. Two solutions are not adequate, because an error in one could not be detected. The three solutions should cover a concentration range less than and greater than the unknown.

   (c) A volume of 2.00 mL of the 0.100 *M* solution should be diluted to 100.0 mL with deionized water. This results in a 0.00200 *M* solution.

   (d) Once the absorbances of the known solutions are plotted against their concentrations, the concentration of the unknown solution can be read from the graph or calculated by using the formula $y = mx + b$.

   [LO 1.16 SP 4.2, 5.1]

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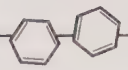

3. (a) Energy of C 1s = photon energy - energy of ejected electron
2.382×10^{-16} J – 1.911×10^{-16} J = 0.471×10^{-16} J

(b) 0.471×10^{-16} J/e X 6.022×10^{23} electrons/mol X 1 kJ/1 $\times 10^{3}$ J = 2.836×10^{4} kJ/mol

(c) K.E. = 1/2 mv^2. Therefore, 1.911×10^{-16} kg m^2/s^2 = 1/2 $(9.11 \times 10^{-31}$ kg) v^2
$v^2 = 2(1.911 \times 10^{-16}$ kg $m^2/s^2)/ (9.11 \times 10^{-31}$ kg)
$v = (4.20 \times 10^{14})^{1/2}$ v = 2.05×10^{7} m/s

(d) Ratio = 2.836×10^{4} kJ/mol/1086 kJ/mol = 26/1

[LO 1.7 SP 5.1]

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CHAPTER 2

CHEMICAL BONDING

1. Aluminum is an active metal, part of group III on the Periodic Table, and is held together by metallic bonding. Choice (A) has ionic bonds, choice (B) has metallic bonds, choice (C) includes covalent bonds between all atoms, and choice (D) has covalent bonds between atoms but intermolecular forces between molecules.

   The correct answer is (B).

   [LO 2.27 SP 1.1]

2. Carbon dioxide is a molecular solid made of nonpolar molecules, held together only by IMFs. Choice (A) has ionic bonds, choice (B) has metallic bonds, choice (C) includes covalent bonds between all atoms, and choice (D) has covalent bonds between atoms but intermolecular forces between molecules.

   The correct answer is (D).

   [LO 2.30 SP 1.1, 6.2, 7.1]

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3. Sucrose is a large organic molecule including covalent bonds and those molecules are held together by weak IMFs. Choice (A) has ionic bonds, choice (B) has metallic bonds, choice (C) includes covalent bonds between all atoms, and choice (D) has covalent bonds between atoms but intermolecular forces between molecules.

   The correct answer is (D).

   [LO 2.32 SP 1.1, 6.2, 7.1]

4. Ammonium nitrate is comprised of ammonium cations and nitrate anions. Although the bonding within each polyatomic ion is covalent, the ions attract each other by the electrostatic attraction known as an ionic bond. Choice (A) has ionic bonds, choice (B) has metallic bonds, choice (C) includes covalent bonds between all atoms, and choice (D) has covalent bonds between atoms but intermolecular forces between molecules.

   The correct answer is (A).

   [LO 2.24 SP 1.1, 6.2, 7.1]

5. The carbon atoms in graphite show sp^2 hybridization so each carbon atom is bonded covalently to three other carbon atoms in a plane. These layers of carbons bond with other layers by weak π bonds. Choice (A) has ionic bonds, choice (B) has metallic bonds, choice (C) includes covalent bonds between all atoms, and choice (D) has covalent bonds between atoms but intermolecular forces between molecules.

   The correct answer is (C).

   [LO 2.29 SP 1.1]

6. Trigonal bipyramidal geometry is a result of five bonding pairs of electrons arranged around a central atom. This hybridization is dsp^3. Answers (A), (B), and (C) all can be explained as molecular geometries formed from octahedral electron pair geometry, each with d^2sp^3 hybridization.
   (Note: Expanded octet hybridizations are no longer included in the revised curriculum, but are still included, *along with shapes* in ACS, SAT II and many regional exams.)

   The correct answer is (D).

   [LO 2.21 SP 1.4]

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7. Homonuclear diatomic species like H_2 are non-polar because each of the two identical nuclei involved in the bond have the same attraction for the shared bonding pair of electrons. Thus there is no difference between the electronegativities of the two atoms involved in the bond. Choices (A), (B), and (C) each are heteronuclear diatomic species and each shows a difference in electronegativity between the two atoms, thus leading to a dipole in the molecule.

   The correct answer is (D).

   [LO 2.18 SP 6.1]

8. The two atoms in the NO molecule contribute eleven valence electrons to the structure and no version can be drawn to give eight electrons to both nuclei. The Lewis structure technique does not work well with species with an odd number of electrons since electrons are assigned as bond pairs or non-bonding pairs.

   The correct answer is (D).

   [LO 2.21 SP 1.4]

9. The central sulfur atom in SO_2 is surrounded by a single bond to an oxygen atom, a double bond to an oxygen atom, and a lone (non-bonding) pair of electrons. This is a bent linear structure. Choice (A) shows linear geometry, choice (B) pyramidal geometry, and choice (C) a tetrahedral configuration.

   The correct answer is (D).

   [LO 2.21 SP 1.4]

10. The bond between the central carbon in the hydrogen carbonate anion and the oxygen with a hydrogen bonded to it is a single bond. The two remaining bonds from carbon to oxygen are represented as resonating between a single bond and a double bond.

    The correct answer is (D).

    [LO 2.24 SP 1.1, 6.2, 7.1]

11. Electrostatic attraction (an ionic bond) brings the sodium cation and the hydrogen carbonate anion together.

    The correct answer is (A).

    [LO 2.23 SP 1.1]

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12. The oxygen-to-hydrogen bond in the hydrogen carbonate anion is always a single covalent bond.

    The correct answer is (B).

    [LO 2.21 SP 1.4]

13. Choice (A) refers to a tetrahedral electron pair and molecular geometry. Choice (B) also has four total pairs but the combination of three bond pairs and one lone pair refers to pyramidal molecular geometry. Although both (C) and (D) have a total of four electron pairs, choice (C) leads to bent linear molecular structure, while choice (D) would be a linear molecular geometry. In water, the central oxygen is surrounded by two bonding pairs of electrons and two lone (non-bonding) pairs. The lone pairs repel the bonding pairs such that they are forced from the 109.5° found in a tetrahedron to the 105° angle of a bent linear structure.

    The correct answer is (C).

    [LO 2.21 SP 1.4]

14. Choice (A) refers to a tetrahedral electron pair and molecular geometry. Choice (B) also has four total pairs but the combination of three bond pairs and one lone pair refers to pyramidal molecular geometry. Although both (C) and (D) have a total of four electron pairs, choice (C) leads to bent linear molecular structure, while choice (D) would be a linear molecular geometry. In ammonia, the central nitrogen is surrounded by three bonding pairs of electrons and one lone (non-bonding) pair. The lone pair repels the bonding pairs such that they are forced from the 109.5° found in a tetrahedron to the 107°angle of a pyramidal structure.

    The correct answer is (B).

    [LO 2.21 SP 1.4]

15. Choice (A) refers to a tetrahedral electron pair and molecular geometry. Choice (B) also has four total pairs but the combination of three bond pairs and one lone pair refers to pyramidal molecular geometry. Although both (C) and (D) have a total of four electron pairs, choice (C) leads to bent linear molecular structure, while choice (D) would be a linear molecular geometry. The tetrachloromethane molecule has four chlorine atoms arranged symmetrically around the central carbon atom to form a tetrahedron. The bond angle is found to be 109.5°.

    The correct answer is (A).

    [LO 2.21 SP 1.4]

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16. Choice (A), the seesaw configuration, arises when a total of five pairs of electrons are arranged as four bond pairs and one lone pair. Choice (B), the T-shaped configuration, also has five total pairs of electrons but they are arranged as three bond pairs and two lone pairs. Choice (C), the tetrahedral structure, has a total of four pairs of electrons. Choice (D), the trigonal planar arrangement, is a result of a total of three pairs of electrons. Boron has three valence electrons and undergoes sp^2 hybridization to form the planar trigonal planar configuration.

The correct answer is (D).

[LO 2.21 SP 1.4]

17. Choice (A), the seesaw configuration, arises when a total of five pairs of electrons are arranged as four bond pairs and one lone pair. Choice (B), the T-shaped configuration, also has five total pairs of electrons but they are arranged as three bond pairs and two lone pairs. Choice (C), the tetrahedral structure, has a total of four pairs of electrons. Choice (D), the trigonal planar arrangement, is a result of a total of three pairs of electrons. The central iodine atom has dsp^3 hybridization. Since it has two non-bonding pairs of electrons and three bonding pairs, shared with fluorine atoms, it adopts a T-shaped configuration, a variation on the trigonal bipyramidal structure.

The correct answer is (B).

[LO 2.21 SP 1.4]

18. Choice (A), the seesaw configuration, arises when a total of five pairs of electrons are arranged as four bond pairs and one lone pair. Choice (B), the T-shaped configuration, also has five total pairs of electrons but they are arranged as three bond pairs and two lone pairs. Choice (C), the tetrahedral structure, has a total of four pairs of electrons. Choice (D), the trigonal planar arrangement, is a result of a total of three pairs of electrons. The central sulfur atom has dsp^3 hybridization. It fills the five hybrid orbitals with four bond pairs to fluorine atoms and has one non-bonding lone pair of electrons. The resulting molecular geometry is called see-saw.

The correct answer is (A).

[LO 2.21 SP 1.4]

19. Choice (A) could be correct for an ionic solid but xenon is comprised of atoms. Choices (B) and (D) are impossible since xenon is not an ionic solid.

The correct answer is (C).

[LO 2.21 SP 1.4]

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20. Beryllium is electron deficient in this molecule because it has only two valence electrons to form two covalent bonds with fluorine atoms, forming a linear structure.

    The correct answer is (A).

    [LO 2.21 SP 1.4]

21. Boron is electron deficient here and does not end up with a complete octet of electrons. Rather it forms three covalent bonds with hydrogen atoms to form a trigonal planar molecule.

    The correct answer is (D).

    [LO 2.21 SP 1.4]

22. The central bromine has three bond pairs of electrons and two non-bonding pairs. This gives a T-shaped structure.

    The correct answer is (C).

    [LO 2.21 SP 1.4]

23. The oxygen atom in the water molecule has sp^3 hybridization. It forms two covalent bonds with hydrogen atoms and also has two non-bonding pairs. This leads to a bent linear structure.

    The correct answer is (B).

    [LO 2.21 SP 1.4]

24. Sulfur trioxide shows trigonal planar geometry and includes resonance among two single bonds and one double bond.

    The correct answer is (D).

    [LO 2.21 SP 1.4]

25. Lone pairs from the cyanide ligands (the Lewis base) form a bond with empty orbitals in the iron(III) cation, the Lewis acid. In this expanded octet, six equivalent bonds are formed (d^2sp^3 hybridization). All bond angles are 90°.

    The correct answer is (B).

    [LO 2.21 SP 1.4]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) Each of the halogens I_2 and Cl_2 has a single covalent bond between two atoms. Since each is a homonuclear diatomic structure, there is no difference in electronegativity between the two atoms and the resulting structure is non-polar. Thus the only intermolecular force between adjacent molecules is the London dispersion force, weakest of the IMFs. Because the iodine structure has many more electrons than the chlorine structure (106 vs. 34), more pronounced temporary dipoles occur and the London forces are stronger. Stronger IMFs lead to higher melting points because more kinetic energy is required to overcome the IMF.

[LO 2.19 SP 1.1, 1.4, 7.1]

(b) In order for electrical conduction to occur, there must be free electrons or ions to move. Solid or molten silver allows electrical conduction via movable electrons, explained by the "sea of electrons" model or band theory. Solid silver nitrate has no free electrons or movable charged particles so it is a non-conductor. When melted, its ions can move. When dissociated into its ions in aqueous solution, there are movable ions. So silver nitrate will conduct electricity when melted or in solution.

[LO 2.28 SP 1.1, 6.2, 7.1]

(c) Although the greater molecular mass (and therefore greater number of electrons) in H_2S might suggest a greater London attractive force, the more pronounced polarity of the H_2O molecule leads to the exaggerated form of dipole attractions known as "hydrogen bonding". H_2S has dipole attractive forces that are not as strong as those of water. This greater IMF causes a higher normal boiling point in water than in hydrogen sulfide.

[LO 2.19 SP 1.1, 1.4, 7.1]

(d) The difference in electronegativity between sodium and arsenic is sufficient to indicate an ionic bond and three sodium atoms lose an electron each to the arsenic atom to form the arsenide anion. Arsenic forms three covalent bonds with chlorine atoms to form a pyramidal structure.

[LO 2.17 SP 6.4]

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2. (a) The Lewis structure of carbonate anion shows single bonds to two oxygen atoms and a double bond to another.

[LO 2.21 SP 1.4]

(b) The central carbon atom will have sp^2 hybridization plus a delocalized π bond. Thus the species should show the trigonal planar configuration with 120° between adjacent oxygen atoms. Each of the three bonds is actually equivalent and the bond length is intermediate between a single and a double bond (but closer to the length of a single bond).

[LO 2.21 SP 1.4]

(c) The carbon and three oxygen atoms are all planar with a sigma bond from the cental carbon atom to each one of the three oxygen atoms. One *p* orbital is not hybridized and extends up and down from the plane of the molecule. The overlapping *p* orbitals share a pair of electrons around and over the three bonding regions of the species.

[LO 2.21 SP 1.4]

(d) The lattice points of solid calcium carbonate are occupied by calcium cations (Ca^{2+}) and carbonate anions (CO_3^{2-}).

[LO 2.24 SP 1.1, 6.2, 7.1]

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3. (a) The azide anion shows *sp* hybridization around the central nitrogen with a π bond on each side. Thus it looks like $[\underline{\overline{N}} = N = \underline{\overline{N}}]^-$ with two lone pairs on each outer nitrogen. The electron pair geometry is linear, as is the molecular geometry. The triiodide anion, I_3^-, exhibits trigonal bipyramidal electron pair geometry, and linear molecular geometry.

[LO 2.21 SP 1.4]

(b) Neither of the two anions is polar since non-bonding electron pairs are distributed equally in each.

[LO 2.21 SP 1.4]

(c) Only the azide anion has delocalized π bonds as non-hybridized *p* orbitals overlap.

[LO 2.21 SP 1.4]

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CHAPTER 3

THE GAS PHASE

1. 14 g of N_2 molecules is one-half mole. This is the smallest number of moles; hence it is also the smallest number of molecules. Choice A, 6.0 g H_2, is equal to 3.0 moles of H_2. Choice C, 17 g NH_3, is 1.0 mole of NH_3. Choice D, 34 g H_2S, is equal to 1.0 mole of H_2S. The number of molecules = (# of moles)(6.02×10^{23} molecules/mole)

   The correct answer is B.

   [LO 2.1 SP 6.4, 7.1]

2. HCl, CO and H_2 all contain two atoms per molecule. Neon exists as individual atoms.

   The correct answer is D.

   [LO 2.1 SP 6.4, 7.1]

3. At the same temperature and pressure, the gases have the **same** average kinetic energy, so the product of $\frac{1}{2}$ mv^2 is the same for all four gases. Therefore, the gas with the smallest molar mass will have the highest velocity.

   The correct answer is B.

   [LO 2.4 SP 1.4, 6.4]

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4. $NH_3(g) + H_2O \rightarrow NH_4^+(aq) + OH^-(aq)$ showing how a basic solution is formed. CO_2 gas is a non-metallic oxide, (an acid anyhydride), and will dissolve in water according to the equation $CO_2(g) + H_2O \rightarrow HCO_3^-(aq) + H^+(aq)$, resulting in an acidic solution. Choice (D), C_4H_{10}, does not dissolve in H_2O.

The correct answer is (B).

[LO 2.1. SP 6.4, 7.1]

5. CO_2 gas is not flammable- it does not support combustion. A glowing splint will go out in a CO_2 environment, making it useful in numerous fire extinguishers. NH_3 is a gas with a pungent odor. C_4H_{10} is butane, which is found in grilling gas tanks and cigarette lighters. It is highly combustible.

The correct answer is (A).

[LO 2.1 SP 6.4, 7.1]

6. At the same temperature and pressure, the gases have the same average kinetic energy (K.E.). K.E. = ½ mv^2. ½ mv^2 Ne = ½ mv^2 SO_3. The molar mass, m, for Ne is 20; the molar mass of SO_3 is 80. ½ · $20v^2$ Ne = ½ 80 v^2 SO_3. The $v^2_{Ne} = 4 \cdot v^2$ SO_3.The $\sqrt{4}$ is 2, so the velocity of Ne is twice the velocity of SO_3. This is a ratio of 2:1.

The correct answer is (C).

[LO 2.6 SP 2.2, 2.3]

7. The volume of a gas is directly proportional to the temperature, but for true proportionality to exist, the Kelvin (absolute) scale must be used. After converting the temperatures using K = °C + 273, the Kelvin temperature changes from 300 K to 600 K. If the absolute temperature doubles, the volume will double.

The correct answer is (C).

[LO 2.6 SP 2.2, 2.3]

8. Ideal gases are those with molecules sufficiently **far apart** such that there are no significant attractions between molecules. The conditions leading to the largest expansion of a gas (the largest volume) are low pressure and high temperature.

The correct answer is (A).

[LO 2.2 SP 7.2]

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9. 0.40 moles + 0.50 moles = total # of moles = 0.90 moles of gas. He represents 4/9 of the total number of moles of gas and 4/9 of the total molecules. It will, therefore, exert 4/9 of the total pressure → 4/9 × 0.90 atm = 0.40 atm. Answer A would result if one took 0.40 × .90 atm, but He is not 40% of the total moles.

   The correct answer is (B).

   [LO 2.6 SP 2.2, 2.3]

10. The pressure exerted by a gas is directly proportional to its temperature, so if the temperature doubles, the pressure exerted by a gas will double. The pressure is inversely proportional to the volume, so if the volume is tripled, the pressure drops to 1/3 the original P. The logic pathway becomes $P_{initial} \times 2 \times 1/3 = 2/3\ P_{initial}$. For answer D to be true, both volume and temperature would have to be directly proportional ($2 \times 3 = 6.0$). For C to be true the temperature would need to be inversely proportional to pressure and the volume directly related to pressure.

    The correct answer is (B).

    [LO. 2.6 SP 2.2, 2.3]

11. Charles Law. As the temperature of a gas increases, at constant pressure, the volume of the gas increases, so they are directly related. The Ideal gas law, PV = nRT, contains quantities that are both directly and inversely proptional to pressure. Graham's law shows that as the mass of a gas increases, the more slowly the molecules move, illustrating an inverse relationship. Hess's law refers to the additivity concept with heats of reaction, and heats of reaction are standardized in terms of heat per 1 mole.

    The correct answer is (D).

    [LO. 2.6 SP 2.2, 2.3]

12. The can implodes (collapses inward) due to rapid condensation of the inside water vapor. As the can of water is heated to boiling, the air in the can is driven out of the can and is replaced with gaseous water vapor molecules. When the temperature of the water drops suddenly in the bucket of cold water, the water vapor condenses. There is no longer much gas remaining inside the can to equalize the inside pressure with the room pressure, so the can implodes (collapses inward).

    The correct answer is (C).

    [LO 2.5 SP 1.3, 6.4, 7.2]

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13. K.E. = kT, so temperature is directly proportional to the kinetic energy. For the direct relationship between temperature and K.E to be valid, the temperatures need to be converted to kelvins. When the °C are converted, they become 303 K and 333 K, respectively. Applying Charles' Law [$V_1/T_1 = V_2/T_2$] the new volume will increase (heating, not cooling) by a factor of 333/303.

The correct answer is (B).

[LO 2.6 SP 2.2, 2.3]

14. When gases are dissolved in water and the temperature of the solution is increased, gases absorb the heat; their K.E. rises, and the gas molecules are more likely to escape the solution, resulting in **decreased** solubility. Answers (A) and (B) are, therefore, incorrect. CO_2 gas is a non-metallic oxide (an acid anyhydride) and will dissolve in water according to the equation $CO_{2(g)} + H_2O \rightarrow HCO_3^- (aq) + H^+ (aq)$. This accounts for the acidic nature (C) of the resulting solution. As long as the water is distilled, no carbonate (CO_3^{2-}) precipitates will form, so answer (D) is incorrect.

The correct answer is (C).

[LO 2.5 SP 1.3, 6.4, 7.2] [LO 2.4 SP 1.4, 6.4] [LO 2.1, SP 6.4,7.1]

15. In a rigid container, the gas molecules expand to fill the space, making answer (A) incorrect. At constant temperature, the average K.E. remains constant, making answer (C) incorrect. If 10% of the molecules escape, so too, 10% of the total mass of the gas, making answer (D) incorrect. Pressure is force/area and the area inside the tank remains the same. With fewer molecules in the tank, the number of collisions/second against the container wall decreases, so the pressure exerted by the gas decreases.

The correct answer is (B).

[LO 2.5 SP 1.3, 6.4, 7.2]

16. According to the law of partial pressures, $P_{total} = 751.0 \text{ mm Hg} = P_{H_2} + P_{H_2O}$; $751 - 23.1 = 727.9$ mm Hg.

The correct is (C).

[LO 2.6 SP 2.2, 2.3]

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17. The volume must be measured at a known pressure, and the only known **pressure** is room pressure. When the water level in the tube equals the water level in the battery jar, the pressures pushing down on both columns of water is the same, room pressure. With the tube inverted, neither H_2 nor water molecules can escape, making (C) and (D) incorrect. The volume is measured at room temperature, whether the 2 levels are equal or not, so answer (A) is incorrect.

    The correct answer is (B).

    [LO 2.6 SP 2.2, 2.3] [LO 2.4 SP 1.4, 6.4]

18. The mole ratio and gas volume are the same. $6.0\ \text{L}\ C_2H_6 \times \frac{7\ \text{L}\ O_2}{2\ \text{L}\ C_2H_6} = 21\ \text{L}\ O_2$. The amount of C_2H_6 in the question is triple the coefficients in the balanced equation, so the amount of O_2 required will be triple the amount in the balanced equation. Answer (B) would only double the amount of O_2 needed, and answer (D) would cut the volume of O_2 in half. Answer (C) ignores the stoichiometry of the reaction.

    The correct answer is (A).

    [LO 3.3 SP 2.2, 5.1]

19. 1×10^{23} molecules $C_2H_2 \times \frac{6\ H_2O}{2\ C_2H_6} = 3 \times 10^{23}$ molecules

    The molecule ratio is the same as the mole ratio for gaseous substances.

    The correct answer is (B).

    [LO 1.4 SP 7.1] [LO 2.6 SP 2.2, 2.3] [LO 3.3 SP 2.2, 5.1]

20. The atmosphere consists mainly of N_2 and O_2, with an approximate molar mass of 30. The molar mass of He = 4. The helium density inside the balloon is less than that of the surrounding air, so the less dense matter rises to the top. (D) is incorrect because this is a trapped sample of gas, and diffusion through the membrane of the balloon is very slow and does not account for the instantaneous rising. (B) is incorrect because the helium quickly cools to atmospheric temperature. If answer (C) were the dominant concern, the volume of the balloon would shrink, not expand.

    The correct answer is (A).

    [LO 2.5 SP 1.3, 6.4, 7.2]

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21. The units of molar mass are grams/mole. At 0°C and 1 atm. of pressure, (STP conditions), I mole of any gas will occupy a volume of 22.4 L 2.0 g/L × 22.4 L/mol = (A). Answer (B) is the inverse of the correct set-up. Answer (C) would be the set-up for calculating the density of the gas. Answer (D) is the calculation at room temperature, 25°C, when the volume of 1 mole of any gas is about 24.5 L (RTP–room temperature and pressure conditions)

The correct answer is (A).

[LO 2.6 SP 2.2, 2.3]

22. The only gas with a molar mass close to 44.8 g/mole (the answer determined in question 21: 2.0 g/L × 22.4 L/mol) is C_3H_8 with a molar mass of 44 g/mole.

The correct answer is (D).

[LO 1.2, 1.3, 2.6 SP 2.2, 2.3]

23. Noting the coefficients in the balanced equation, the total moles of product gases = 1 mole N_2 + 3 mole H_2 = 4 moles and so twice the products molecules will exert twice the pressure of the reactants. Answer (D) is incorrect because it cuts the pressure in half. Answer (C) would only be true if there were the same number of moles (and therefore, molecules) on each side of the equation. Answer (B) ignores the N_2 on the product side.

The correct answer is (A).

[LO 3.4 SP 2.2, 5.1, 6.]4 [LO 2.6 SP 2.2, 2.3]

24. The higher the temperature, the greater the kinetic energy (K.E.) of the gas. K.E. = $\frac{1}{2}mv^2$ or $\frac{1}{2}mv^2$.

Mass does not change at hotter temperatures, so if K.E. increases, the velocity of the molecules increases. (A) is incorrect, because at constant temperature, heavier molecules move more slowly than lighter ones. Answer (B) fails to take into account the temperature of the molecules as well as their mass. Answer (D) is incorrect, because the pressure exerted by the gas is a function of the number of molecules/sec colliding against the container wall. If a given container volume expands, the # of collisions/sec (pressure) decreases.

The correct answer is (C).

[LO 2.4 SP 1.4, 6.4]

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25. Consider the Combined Gas Law, where the volume stays the same (in the rigid container).

$$P_1 V_1/T_1 = P_2 V_2/T_2$$

If the absolute temperature doubles, the average kinetic energy doubles, so the speed $\left(\text{K.E.} = \frac{1}{2}mv^2\right)$ and the pressure will also double. In a rigid container, the volume remains the same, and no mass enters or leaves the container, so the density (mass/volume) of the gas (C) is unchanged.

The correct answer is (C).

[LO 2.4 SP 1.4, 6.4] [LO 2.6 SP 2.2, 2.3]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) FALSE. According to Avogadro's Hypotheses, at the same temperature and pressure, equal volumes of gases are equal because they contain the same number of molecules. If the number of molecules is the same, the number of moles of each gas is the same.

   (b) TRUE. At the same temperature, the gases have the same average kinetic energy (K.E.). The K.E. of a gas = $\frac{1}{2}mv^2$, so = $\frac{1}{2}mv^2$ of N_2 = $\frac{1}{2}mv^2$ of SO_3. Because SO_3 has the larger mass, the velocity (speed) of the SO_3 will be lower.

   (c) FALSE. The two gases exist at the same temperature, so they possess the same average K.E. (K.E. = kT)

   (d) FALSE. The samples, as explained in A, contain the same number of molecules. Therefore, the same number of moles exists in each container. The molar mass of N_2 = 28; the molar mass of SO_3 = 80, so, with a mole ratio of 1:1, the mass ratio will be 28: 80, not 1:1.

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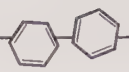

2. (a) $PV = nRT$, so $n = PV/RT = \dfrac{800\text{mm}/760\text{mm/atm} \times 0.560\text{ L}}{0.082\text{ L atm/mol K} \times 273\text{K}} = 0.0263\text{ mol}$

   (b) Molar Mass = grams/mole $= \dfrac{1.58\text{ g}}{0.0263\text{ mol}} = 60.1\text{ g/mol}$

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3. (a) $2\,NH_4NO_3(s) \rightarrow 2\,N_2(g) + 4\,H_2O(g) + O_2(g)$

(b) $4.00\text{ g } NH_4NO_3 \times \frac{1\text{ mole } NH_4NO_3}{80.\text{ g } NH_4NO_3} \times \frac{7\text{ mole products}}{2\text{ mole } NH_4NO_3} = 0.175\text{ mole products.}$

(c) $0.175\text{ mol} \times 6.02 \times 10^{23}\text{ molecules/mol} = 1.05 \times 10^{23}\text{ molecules total for the product gases.}$

(d) $PV = nRT$ so

$$V = \frac{nRT}{P}$$

$$= \frac{(0.175\text{ mol})\left(\frac{0.082\text{ L atm}}{\text{mol K}}\right)(527\text{ K}).}{\left(745\text{ mm Hg} \times \frac{1\text{ atm}}{760\text{ mm Hg}}\right)}$$

$$= 7.71\text{ L}$$

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4. (a) 8.25 g/208.2 g/mol = 0.0396 mol

$$PV = nRT,\ P = nRT/V = \frac{0.039\ \text{mol} \times 0.082\ \text{L atm/mol K} \times 400\ \text{K} =}{2.00\ \text{L}}$$

$$= \mathbf{0.649\ atm}$$

(b) Let X = Partial pressure of PCl_3, so X also = partial pressure Cl_2
From above, PCl_5 becomes 0.649 atm –X; 0.900 atm = 0.649 atm –X + X + X
X = 0.251 atm = P_{PCl_3};
$P_{PCl_5} = 0.649 - X = 0.649 - 0.251 =$ **0.398 atm**

Note to the Student: This question is the type which could likely qualify as the one in which significant digits *would* be evaluated. Depending upon earlier roundings, the answer could be written as 0.400 atm.

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CHAPTER 4

INTER-MOLECULAR FORCES AND CONDENSED PHASES OF MATTER

1. The boiling point temperature as well as the condensation temperature occurs at the higher plateau temperature, in this case, 80°C.

   The correct answer is (B).

   [LO 3.11 SP 1.5 4.4]

2. The freezing point is identified by the lowest plateau temperature in the cooling process.

   The correct answer is (C).

   [LO 3.11 SP 1.5, 4.4]

3. Potential energy regions are those which do NOT involve a change in temperature, in this case, Regions II and IV. The molecules are condensing from the gaseous phase (where there are no attractive forces between the molecules of an ideal gas) into the liquid phase, where attractive forces between molecules are becoming appreciable. These changes are larger than the change in attractive forces from the liquid to solid phase.

   The correct answer is (C).

   [LO 3.11 SP 1.5, 4.4]

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4. After the gas phase condenses in Region II, the liquid cools down to room temperature, or to its freezing point. The liquid's temperature drop occurs in Region III.

   The correct answer is (B).

   [LO 3.11 SP 1.5, 4.4]

5. Temperature is a measure of kinetic energy, as defined in the equation, K.E. = kT. Therefore the region of highest kinetic energy is the region with the highest temperature: Region I. Regions III and V exist at lower temperatures.

   The correct answer is (D).

   [LO 3.11 SP 1.5, 4.4]

6. The liquid with the highest vapor pressure at room temperature is the one which has evaporated to the greatest extent, which is the result of the weakest attractive forces between molecules. Rubbing alcohol will evaporate from the same surface (like a driveway) far more readily than motor oil will. In (A) and (C), water evaporates more readily than motor oil or mineral oil; and in (D), perfume will evaporate more readily (think human skin) than will milk.

   The correct answer is (B).

   [LO 2.32 SP 1.1, 6.2, 7.1] [LO 5.9 SP 6.4]

7. The heat of sublimation is the temperature at which a solid is converted to a gas. The heat of combustion is the heat released when one mole of a substance reacts with oxygen and burns. The heat of vaporization is the heat required to convert one mole of a liquid into one mole of gas. The heat of fusion is the same as the heat of solidification (with an opposite sign) - the heat required to melt one mole of solid at its melting point.

   The correct answer is (A).

   [LO 5.6 SP 2.2, 2.3]

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8. Molar mass, by itself, is never a measure of attractive forces between molecules, although admittedly, the trends may parallel one another with non-metals. Both C_3H_8 and CH_4 are non-polar molecules, eliminating answer (C). Neither molecule contains the elements, fluorine, oxygen or nitrogen, eliminating the possibility of "hydrogen bonding," answer (D). However, the C_3H_8 molecules have a larger surface area and more outer electrons, which become "polarizeable electrons." Both these factors contribute to stronger "instantaneous attractions" arising between the C_3H_8 molecules, a measure of Van der Waal forces, or London dispersion forces.

   The correct answer is (B).

   [LO 2.16 SP 6.2]

9. The highest melting points are typically found in network covalent substances like diamond. The element Ge is located in the same Family (IVA) of metalloids on the Periodic Table and is capable of forming the same types of networks that carbon atoms form in diamonds.

   The correct answer is (A).

   [LO 5.9 SP 6.4] [LO 2.30 SP 1.1, 6.2, 7.1]

10. The substances with network covalent structures, again, like diamond, made up of carbon atoms in a 3-dimensional network are typically the hardest substances. The element Ge is located in the same Family (IVA) of metalloids on the Periodic Table and is capable of forming the same types of networks with very strong bonds that carbon atoms form in diamonds.

    The correct answer is (A).

    [LO 5.9 SP 6.4] [LO 2.30 SP 1.1, 6.2, 7.1]

11. The substance with the lowest heat of vaporization at 1 atm of pressure is the one with the weakest attractive forces between molecules. These substances are usually the non-polar molecular substances, which are made up of neutral molecules. Propane, C_3H_8, is a non-polar molecule that does not contain fluorine, oxygen or nitrogen (needed for "hydrogen bonding").

    The correct answer is (D).

    [LO 2.32 SP 1.1, 6.2, 7.1]

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12. Metals exhibit high conductivity in the solid state due to their mobile surface electrons. In ionic compounds in the solid state, the electrons are tightly bonded to the individual ions, which have stable ("octet") electron configurations. However, when melted, the ions are mobile and readily attracted to charged electrodes or terminals inserted into the melted compounds. The ability of charged ions to migrate through a distance creates electrical conductivity in the melted state. The correct answer is the ionic compound, LiCl, answer (C).

    The correct answer is (C).

    [LO 2.24 SP 1.1, 6.2, 7.1]

13. In "hydrogen bonding," as now spelled out in the revised AP Chemistry curriculum, the hydrogen atoms in molecular compound are strongly attracted to the highly electronegative fluorine, oxygen or nitrogen atoms in an adjacent molecule. The only molecular substance above in which this combination of atoms exists is Glycerol, $C_3H_5(OH)_3$. Hydrogen must be in a polar bond with the elements F, O, or N to be able to form H–bonding with an adjacent molecule.

    The correct answer is (B).

    [LO 2.32 SP 1.1, 6.2, 7.1]

14. Vaporization involves molecules moving from the liquid phase to the gaseous phase. Evaporation is one form of vaporization (boiling is another). Excitation is the process in which electrons absorb incoming energy and move to higher energy levels in an atom. Sublimation is the process in which a solid moves directly from the solid into the gas state (like dry ice). This process accounts for the shrinkage of ice cubes and snowmen.

    The correct answer is (B).

    [LO 3.1 SP 1.5, 7.1] [LO 2.32 SP 1.1, 6.2, 7.1]

15. Approximating the temperature on the graph at 25°C , the liquid which would be expected to have the highest equilibrium vapor pressure at room temperature is $CHCl_3$. The vapor pressure at room temperature is approximately 200 Torr for $CHCl_3$, but the value of the other liquids on the graph, at this temperature, are visibly lower. CCl_4, with an additional chlorine, has more surface (valence) electrons (also referred to as "polarizable "electrons). H_2O is a polar molecule, which exhibits strong "hydrogen bonding," resulting in the lowest evaporation rate of these three at room temperature.

    The correct answer is (A).

    [LO 2.16 SP 6.2] [LO 2.32 SP 1.1, 6.2, 7.1]

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16. In answer (A), both are metallic substances, each contributing one valence electron to the delocalized "sea of electrons" holding the atoms together, much like a blanket, in the solid form. Rb metal has a larger radius, resulting in a lower surface charge density per atom, so atoms of Rb would require a lower energy to separate or melt. The same reasoning would apply to answer (D), where atoms of Fe would have a smaller radius and each atom would contribute two valence electrons to the sea of electrons in contrast to Cs metal, with one valence electron and a larger radius. In answer (C), both compounds are molecular compounds made up of neutral molecules. The larger molecule, CS_2, would have more surface area in contact with neighboring CS_2 molecules, resulting in more opportunity for instantaneous attractions to arise between molecules. These stronger inter-molecular forces would result in lower evaporation rates and require higher melting points. In answer (B), with LiCl , an ionic crystal, one is comparing the stronger forces of attraction between oppositely charged ions to the weak attractive forces between neutral, non-polar molecules. The LiCl will require greater heat to separate the ions.

The correct answer is (B).

[LO 2.28 SP 1.1, 6.2, 7.1]

17. Answer (B) ignores the fact that H_2O molecules have more valence electrons than CH_4 (Bunsen burner gas). Answer is (C) is incorrect because it is not true. Water molecules exhibit hydrogen bonding between one another, an extreme type of dipole-dipole attractions, but CH_4 are non-polar molecules that do not exhibit dipole-dipole attractions. Answer (D) is also false because "hydrogen bonding" does NOT exist between CH_4 molecules: the CH_4 molecule does not contain any of the F, O, or N atoms needed for "hydrogen bonding." However with the polar H_2O molecules, the dipole-dipole attractions between the H_2O molecules are significantly stronger than the attractions between H_2O and the non-polar CH_4 molecules. Therefore CH_4 will not be appreciably soluble in (solvated by) water molecules.

The correct answer is (A).

[LO 2.15 SP 1.4, 6.2]

18. Covalent network solids typically consist of C, Si or Ge atoms, each with four valence electrons. These atoms have high ionization energies, which do not lead to mobile surface electrons found in metallic elements. These mobile surface electrons found in metallic substances readily allow a mechanism for transmitting heat to neighboring atoms, as well as the "pushing" of electrons across the surface, resulting in electrical conductivity and the ability to deform the metal and draw it into wires (ductility). Network covalent crystal will therefore not exhibit any of these characteristics. The strongly bonded network structure, however, will result in the extreme hardness and high melting points that we do find in networks like diamond (C atoms) and quartz (Si atoms).

The correct answer is (C).

[LO 2.22 SP 4.2] [LO 2.30 SP 1.1, 6.2, 7.1]

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19. Copper wire is made up of solid Cu atoms. With relatively low ionization energy, and a shiny surface, copper is classified as a metallic substance.

    The correct answer is (B).

    [LO 2.2 SP 4.2]

20. Carbon dioxide, also known as dry ice, is made up of neutral, non-metallic CO_2 molecules with a O-C-O bond angle of 180°. The dipole moments cancel out, so the molecules are non-polar.

    The correct answer is (D).

    [LO 2.2 SP 4.2]

21. Benzene liquid, C_6H_6, is similar to CO_2 discussed in question 20 above. It is made up of neutral molecules, but exists in a symmetrical, hexagonal shape. Because the molecular structure IS symmetrical, the molecule is non-polar and the electrons are not as polarizable as those in CO_2.

    The correct answer is (D).

    [LO 2.2 SP 4.2]

22. Lithium nitrate is made up of positive Li^+ ions and negative NO_3^- ions. Both are univalent, resulting in the formula, $LiNO_3$. All ionic compounds are solids at room temperature, so solid $LiNO_3$ is therefore classified as an ionic solid. None of the other substances listed as potential answers consists of positive and negative ions.

    The correct answer is (A).

    [LO 2.2 SP 4.2]

23. Powdered graphite, often written as C(*gr*), is made up of carbon atoms with strong bonds in two dimensions and weak bonds between layers. These different forces results in great strength within planes of carbon atoms but weak forces between the planes. This behavior can occur with carbon, silicon or germanium atoms and, in this form, is referred to as planar covalent.

    The correct answer is (C).

    [LO 2.2 SP 4.2]

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24. Inexpensive, sealed hand-boilers work on the principle that the boiling point of a liquid varies as the atmosphere pressure varies. This is because the boiling point of a liquid is defined as the temperature at which the vapor pressure cancels out the atmospheric (ambient) pressure. If the liquid is placed in a hand boiler device, often a narrow glass container, and then the device is hooked to a vacuum pump, the pressure over the liquid can be reduced to a very low pressure, and the device can be sealed off. Now with very little additional heat, like that which can be supplied by a human hand, the vapor pressure rises and is capable of canceling out the low pressure above it. The liquid then begins to boil. This means that answers (C) and (D) are false. The correct answer is (B). Any liquid has an array of boiling points, depending upon the pressure over it. This means that answer (A) is false necessitating a common standard. This results in the term "normal boiling point," the temperature at which a liquid boils when the atmospheric pressure is 1 atmosphere (760 torr).

The correct answer is (B).

[LO 2.16 SP 6.2]

25. Liquified ammonia consists of NH_3 molecules, which contain N–H bonds and one non-bonded pair of electron on the nitrogen atoms, resulting in a polar molecule. The polarity of the molecules leads to dipole – dipole attractions between the molecules, so answer (B) is false, because these forces DO exist between NH_3 molecules. Because the NH_3 are neutral and polar, we have appreciable instantaneous London Dispersion forces between the molecules, making answer (C) false as well. In highly polar bonds in "hydrogen bonding," as now spelled out in the revised AP Chemistry curriculum, the hydrogen atoms in a molecular compound are strongly attracted to the highly electronegative fluorine, oxygen or nitrogen atoms in an adjacent molecule. Therefore NH_3 molecules will exhibit "hydrogen bonding," making answer (D) false. The sharing of electrons between nitrogen and hydrogen atoms is covalent bonding, not ionic bonding.

The correct answer is (A).

[LO 2.32 SP 1.1, 6.2, 7.1]

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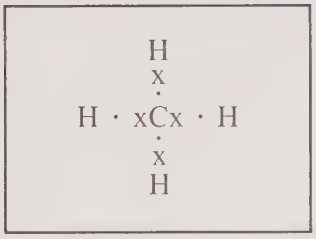
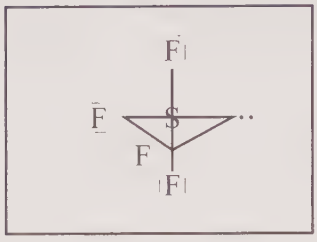
CONSTRUCTED-RESPONSE SOLUTIONS

1. (a)



CH_4

Shape tetrahedral



SF_4

Shape see-saw

[LO 2.21 SP 1.4]

(b) i. One factor is molecular polarity. CH_4 is a non-polar molecule, while SF_4 is a polar molecule. The dipole-dipole attractions between SF_4 molecules result in stronger attractions, which, in turn, require more heat to separate. More energy needed translates to a higher boiling point. The existence of a lone pair of non-bonded electrons on sulfur also results in SF_4 being polar. Either factor under the "polarity" discussion is acceptable.

A second factor is the number of valence or outer electrons. The fluorine atoms each contain 7 valence electrons, while the hydrogen atoms in CH_4 contain only one valence electron each. The more outer electrons on the surface of the molecule, the stronger the instantaneous attractions are between the molecules. The stronger the attractions, the more energy that is required to separate the molecules, and the higher the boiling points.

Note: Although SF_4 has a larger molar mass than CH_4, molar mass, in and of itself, is NOT acceptable to AP – it typically correlates to a larger number of electrons, but it is the number of surface electrons as an answer, not larger mass, that earns the credit.

[LO 2.13 SP 1.4] [LO 2.16 SP 6.2]

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ii. Because the SF_4 molecules are polar, as described in Part B, there are dipole-dipole attractions between the SF_4 molecules and the polar H_2O molecules. No such attractions exist between the non-polar CH_4 molecules and the H_2O molecules. Therefore the SF_4 molecules are more readily hydrated (dissolved) than are the CH_4 molecules. In addition, it can be argued that some hydrogen bonding also exists with SF_4 in water, further enhancing its ability to dissolve in water. Because CH_4 does not contain the fluorine, oxygen or nitrogen atoms necessary for "hydrogen bonding," it will not form these additional attractions.

[LO 2.15 SP 1.4, 6.2]

(c) Because of the nature of the dipole-dipole attractions that exist between SF_4 molecules, the attractions of SF_4 molecules to each other are far stronger than the attractions between SF_4 molecules and the non-polar CCl_4. Very little dissolving will occur. However, the Van der Waal attractions between the outer electrons of non-polar CH_4 and the non-polar CCl_4 lead to greater solubility of CH_4 in CCl_4. Note: "Like dissolves like" is a summary of behaviors and does not earn any points as an explanation.

[LO 2.15 SP 1.4, 6.2]

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2. (a) The "normal" vapor pressure refers to vapor pressure exerted at 1 atmosphere of air pressure, 760 torr. Both water and CH_3OH have the polar –OH group, but the non-polar $–CH_3$ end limits the amount of hydrogen in bonding in CH_3OH. There is stronger hydrogen bonding between water molecules, resulting from these strong dipole-dipole attractions. Therefore, individual water molecules have a lower likelihood of overcoming these stronger attractions and evaporating. When evaporation is diminished, the vapor pressure exerted by the liquid is lower.

[LO 2.13 SP 1.4]

(b) Both iodine and chlorine atoms have 7 valence electrons each and neither the I_2 nor the Cl_2 molecule is polar. The difference in melting points arises from the larger surface area in the I_2 molecule, giving rise to greater likelihood of instantaneous attractions of outer electrons to nuclei in adjacent molecules

The nature of contact between Cl-Cl molecules is closer to tangent point contact than in the larger I-I molecule. The evidence for believing this is the fact that Cl_2 is a gas at room temperature and iodine is a dark purple solid. Although the mass of iodine molecules is larger than the chlorine molecules, mass does NOT play any role in these electrons' attractions to adjacent nuclei attractions. Mass arguments will not earn points in the AP assessment of points for a response.

[LO 2.16 SP 6.2]

(c) Both solid silver (Ag) and molten Ag are good conductors of electricity. However, solid silver nitrate, $AgNO_3$, is a good conductor only when melted or dissolved in pure water; as a solid, it is a poor conductor. Silver is a metal, which means the crystal and melted liquid consist of metal atoms with delocalized valence electrons, often referred to as a sea of electrons. This phenomenon is the result of very low ionization energies (relative to the other elements) for metals. These mobile electrons readily lend themselves to being "pushed" across the surface when electricity is supplied via a wire. However, in the solid from, silver nitrate consists of alternating positive silver and negative nitrate ions whose electrons are firmly bonded in stable, octet configurations. Therefore migration of outer electrons does not occur, and no conductivity is detected in the solid form. However, when melted or dissolved in water, the ions are separated from one another and free to migrate towards charged terminals inserted into the vessel. This separation of charges accounts for why $AgNO_3$ does conduct electricity in the molten state or in aqueous solutions.

[LO 2.20 SP 6.2, 7.1]

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(d) Water molecules exhibit "hydrogen bonding," a higher form of dipole-dipole attractions because oxygen is more electronegative than is sulfur. These stronger attractions between H_2O molecules compared to between H_2S require greater energy to overcome. The higher required energy results in a higher boiling point. Note: although the mass of H_2S is higher, it does not play a role in outer electrons → nuclei attractions.

[LO 2.16 SP 6.2]

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3. (a) Carbon atoms in the diamond form a network of covalent bonds between the carbon atoms in all three dimensions. This results in abnormally high hardness, making diamond an excellent cutting tool.. Diamond is one of the few things that can cut into another diamond. However, the carbon atoms in graphite form strong covalent bonds in a two-dimensional surface, but exhibit weak bonds between the planes (a planar covalent solid). This allows for the planes to be readily cleaved from one another, as experienced with the graphite in a "lead" pencil.

[LO 2.30 SP 1.1, 6.2, 7.4]

(b) In water, the polar nature of the water molecule results in the negative nitrate (NO_3^-) forming attractions to the positive (hydrogen) end of the water molecules. In a similar manner, the positive (K^+) potassium ions are readily attracted to the negative (oxygen) ends of the water molecules. The sum of attractions of the individual ions to numerous water molecules is stronger than their attraction to each other so dissociation (solvation) occurs in the water. $KNO_3\,(s) \rightarrow K^+\,(aq) + NO_3^-\,(aq)$. When sucrose, $C_{12}H_{22}O_{11}$, is placed in water, the lack of conductivity indicates that no ions are formed. This means that the attraction of the covalently bonded atoms to each other within the $C_{12}H_{22}O_{11}$ molecules are stronger than the attractions to polar molecules. Therefore, the molecule does not separate into any ions.

[LO 2.2 SP 4.2]

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4. (a) The boiling point is defined as the temperature at which the vapor pressure is equal to (cancels out) the air pressure above the liquid. When the pressure above the liquid is reduced, less vaporization is required in order for the liquid to boil. At the temperature of 10°C, the only liquid with a vapor pressure equal to or above 50 mm Hg is CCl_4. Therefore, the only liquid in which boiling will be observed will be the liquid CCl_4.

   (b) At 25°C three liquids will have vapor pressures equal to or greater than 50 mm Hg. Therefore, with vapor pressure of 59 mm, 114 mm and 94 mm, respectively, the ethyl alcohol, the CCl_4, and the benzene will all be observed to be boiling.

[LO 5.6 SP 2.2, 2,3]

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CHAPTER 5

SOLUTIONS

1. The only concentration unit that can be calculated from just masses of solute and solvent is the mass percent ($mass_1/mass_1 + mass_2$). Molarity, choice (A), requires the molar mass of the solute and the volume of the solution. Molality, choice (B), also requires the molar mass of the solute and mole fraction, choice (D), requires the molar masses of both substances.

   The correct answer is (C).

2. Molarity = mol solute/L solution. Since the volume of a liquid varies with temperature, the value of the molarity, choice (A), will also. Molality, choice (B), which is defined as moles of solute divided by the mass of solvent, was developed as a concentration scale precisely because it doesn't vary with temperature. Mass percent, choice (C), is calculated from masses while mole fraction, choice (D), also requires molar masses. The latter three concentration scales do not vary with temperature as the molarity does.

   The correct answer is (A).

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3. Molarity, choice (A), is not used to determine molar masses by freezing point depression because the molarity of a solution changes concentration with a change in temperature. Thus, the concentration of solute at the freezing point, which is required to calculate the molar mass, would be different than that calculated at the temperature at which the solution was prepared. Molality, choice (B), is used to find molar masses via $\Delta T = k_f m$. This relationship is used because molality is calculated from masses and does not vary with temperature. Mass percent, choice (C), contains no reference to moles as would be needed to calculate the molar mass of solute. By convention, mole fraction, choice (D) is not used because the calculations are unnecessarily complex.

   The answer is (B).

   [LO 3.4 SP 2.2, 5.1, 6.4]

4. In order to calculate the molarity of Li^+ the number of moles of Li_2SO_4 must be calculated from $2.20\ g \times 110\ mol\ gmol^{-1} = 0.020\ mol\ Li_2SO_4$. Because there are two moles of Li^+ ions per mole of Li_2SO_4 there are 0.040 mol of Li^+ ions in 2.20 g. The molarity of Li^+ is found from $0.040\ mol / 0.050\ L = 0.800\ M\ Li^+$, choice (D). Choice (A) is the number of moles of Li_2SO_4, choice (B) is the number of moles of Li^+ ions and choice (C) is the Li_2SO_4 molarity.

   The correct answer is (D).

   [LO 3.3 SP 5.1]

5. pH = 1.00 corresponds to $1 \times 10^{-1} M. [H^+] = 0.10\ mol/L \times 0.200\ L = 0.020\ mol$, choice (A). Choice (B) is the pH multiplied by the volume in L. Choice (C) is the $[H^+]$ divided by the volume and choice (D) is the volume divided by $[H^+]$.

   The correct answer is (A).

   [LO 3.3 SP 5.1]

6. Choice (A) is an equation for the dissolution of solid NaCl. Choice (B) represents a precipitation reaction because a solid is formed from two soluble reactants. Choice (C) is a neutralization reaction in which H^+ and OH^- ions react to for H_2O. An oxidation-reduction reaction requires a change in oxidation number from reactants to products , which occurs when Cl^- ions (in HCl) and OCl^- ions are converted to Cl_2.

   The answer is (D).

   [LO 3.8 SP 6.1]

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7. Choice (A) is an equation for the dissolution of NaCl, choice (C) is a neutralization reaction and choice (D) is an oxidation-reduction. (See answer to q. 6.) Precipitation involves the formation of a solid such as AgCl(*s*).

   The correct answer is (B).

   [LO 6.21 SP 6.4]

8. Acid-base reactions involve the transfer of one or more protons, often with the formation of $H_2O(l)$. Choice (A) is an equation for the dissolution of NaCl, choice (B) represents a precipitation reaction, and choice (D) is an oxidation-reduction reaction. In choice (C), HCl and $Mg(OH)_2$ react to form H_2O, Mg^{2+}, and Cl^- ions.

   The answer is (C).

   [LO 3.7 SP 6.1]

9. The first step in determining the $[Ca^{2+}]$ is to find the number of moles of Ca^{2+} in 1.20 g of $CaCO_3$, which is done by dividing by the $CaCO_3$ molar mass (100 g mol^{-1}) to give 0.012 mol $CaCO_3$. The 1:1 mole ratio of Ca^{2+} / $CaCO_3$ gives 0.012 mol Ca^{2+}. The $[Ca^{2+}] = 0.012 \text{ mol}/0.050 \text{ L} = 0.24\ M$, choice (C). Choice (A) is the result of multiplying the moles of Ca^{2+} by 0.050 L. Choice (B) is the number of moles of Ca^{2+}. Choice (D) results from dividing the volume, 0.050 L, by moles, 0.012 which is the inverse of the correct process.

   The answer is (C).

   [LO 1.19 SP 4.2]

10. Choice (A), a 20% excess (rather than a 10%), would have no effect on the amount of precipitate. Choice (B), a failure to subtract the mass of the filter paper would give a result that is too high, as would choice (C), having an excess of Na_2CO_3. If some of the precipitate was not transferred, the mass (and therefore the Ca^{2+} *M*) would be too low.

    The answer is (D).

    [LO 1.19 SP 4.2]

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11. In order to calculate the $[OH^-]$, the moles of H^+ used in the titration must be found from $0.250\ M\ H_2SO_4 \times 0.02500\ L \times 2H^+/H_2SO_4 = 0.0125\ mol\ H^+$. The moles of OH^- equals the moles of H^+. The $[OH^-]$ is obtained by dividing the moles of OH^- by the volume titrated, i.e. $0.0125\ mol/0.0200 L = 0.625\ M$ base, choice (B). Choice (A) is obtained by neglecting the two protons in H_2SO_4. Choice (C) results from not subtracting the initial volume of H_2SO_4 from the final volume and choice (D) is the result of making the error in (A) and the error in (C).

The answer is (B).

[LO 1.20 SP 4.2, 5.1]

12. Choice (A), doubling the number of drops of indicator will not affect the titration results although it will make the color more intense. Choice (B), using an indicator that changes at pH = 5 rather than at pH = 7 will not affect the results because the titration involves a strong acid and a strong base so both indicators will change on the steep vertical portion of the curve. Choice (C), having water in the titration flask will not affect the results because only the moles of base pipeted into the flask and the moles of acid added from the buret are important. Assuming no air bubble was in the tip at the start of the titration, choice (D), an air bubble in the buret tip will result in a volume of H_2SO_4 that is too high, which will give a high molarity.

The answer is (D).

[LO 1.20 SP 4.2, 5.1]

13. In choice (A) the $[H^+]$ is given as $1 \times 10^{-2}\ M$. Choice (B), $[OH^-] = 1 \times 10^{-3}\ M$, corresponds to $[H^+] = 1 \times 10^{-11}$ (from $[H^+] = 1 \times 10^{-14}/[OH^-]$). Choice (C), pH = 3, corresponds to $[H^+] = 1.0 \times 10^{-3}$ and choice (D), OH = 9 gives a pH = 5 (from pH + pOH = 14) and thus $[H^+] = 1.0 \times 10^{-5}$. The most acidic solution will have the highest $[H^+]$, in this case, choice (A), $1 \times 10^{-2}\ M$.

The answer is (A).

[LO 3.7 SP 6.1]

14. Choice (A) gives a molecular equation with $AgNO_3$, KCl and KNO_3 as solids. Choice (B) shows $KNO_3(aq)$ but has $AgNO_3$ and KCl as solids. Choice (C) shows the correct states for all the species but includes the spectator ions (K^+ and NO_3^-) The net ionic equation summarizes the fact that Ag^+ and Cl^- ions react to give $AgCl(s)$ and omits the non-reacting K^+ and NO_3^- ions.

The answer is (D).

[LO3.2 SP 1.5, 7.1]

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15. Coulomb's Law, $F = q_1 \times q_2 / r^2$, states that the energy of attraction between two charged particles (such as ions) is equal to the product of their charges divided by the square of the distance between them. Assuming little difference in r, KOH, choice (A), with a +1 and −1 ion will have the weakest forces between the ions. K_2SO_4, choice (B), with two +1 ions and a –2 ion will have a lattice energy about twice as large as KOH. The lattice energy for choice (C), $Ca(OH)_2$, with a +2 ion and two –1 ions, will be about twice as large as that for KOH. $CaSO_4$, with a + 2 and −2 ion will have a lattice energy that will be four times that of KOH and two times those of either K_2SO_4 or $Ca(OH)_2$.

The answer is (D).

[LO 2.14 SP 6.4]

16. For a process that occurs with the absorption of energy, the total of any terms that require an input of energy must be greater than the sum of any energy-releasing terms. Therefore, the $M^+ X^-$ interaction, choice (A), which requires the input of energy to separate the ions, must be larger than the energy-releasing terms, M^+--OH_2, choice (B), or X^----HOH, choice (C). The energy associated with hydrogen bonding, choice (D), HOH---OH_2 will be relatively weak.

The answer is (A).

[LO 6.24 SP 1.4]

17. The scheme for the dissolution of $MgF_2(s)$ involves breaking the ions apart and hydrating these gaseous ions. ΔH_{rxn} will equal $\Delta H^\circ_{lat} + [\Delta H^\circ_{hyd}(Mg^{2+}) + 2\Delta H_{hyd}(F^-)]$. $\Delta H^\circ_{rxn} = 2922 + [-179 + 2(-74)]\,\Delta H^\circ_{rxn} = 2922 - 327\,\Delta H^\circ_{rxn} = 2595$ kJ/mol, which is choice (B). Choice (A) incorrectly uses the ΔH_{hyd} for only one F^-. Options (C) and (D) reverse the signs for endothermic and exothermic terms.

The answer is (B).

[LO 5.8 SP 7.1]

18. The data show that the entropy of hydration becomes less negative as the ions become larger, indicating a decrease in order. Options (A) and (B) refer to the amount of heat, which is not directly related to the ΔS° value. If the H_2O molecules were held more tightly to the larger ions, choice (C), ΔS° would become more negative in this direction. The less negative ΔS° values with increasing size, choice (D), correspond to a decrease in order.

The answer is (D).

[LO 6.24 SP 1.4]

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19. $MnO_4^- \rightarrow Mn^{2+}$ ON for Mn in MnO_4^- –1 (charge) = ON Mn + **4**(–2 ON for O) ON = 7
Mn^{2+} ON = 2; 7 → 2 is a gain of 5 electrons, choice (A). Choice (B) has the correct number of electrons but indicates they are lost rather than gained. Choice (C), three electrons are gained, considers only the charges on the ions, not the ONs and indicates that electrons are gained. Option (D), three electrons are lost, would be correct if the O ion were –1 rather than –2.

The answer is (A).

[LO 3.8 SP 6.1]

20. The bonds between N and three Hs are covalent bonds as are those between O and two Hs. The only hydrogen bond is that between the lone pair of electrons on N and one of the Hs in H_2O, choice (A). Choice (B) may refer to the two covalent bonds in H_2O. Choice (C) represents the number of covalent bonds in H_2O and NH_3 and choice (D) is the total number of bonds, covalent as well as hydrogen bonds.

The answer is (A).

[LO 2.8 SP 1.1]

21. Although it is possible to separate two liquids by choice (A), column chromatography or choice (B), filtration, this is not the usual approach. The fact that the two liquids have very similar boiling points rules out choice (D), simple distillation, which is limited to substances with very different boiling points. Fractional distillation is required to separate liquids with similar boiling points.

The answer is (C).

[LO 2.10 SP 4.2]

22. Option (A), column chromatography, would not be a good choice to separate a solid from a solution, which usually requires that a solid be dissolved in the liquid before fixing it on the column and adding solvent to move it along. Although a distillation could be used to separate a liquid from a solid by heating, options (C), fractional distillation, and (D), simple distillation, would not be the optimum methods to achieve this separation. Solids can be separated from solutions most easily by filtration.

The answer is (B).

[LO 2.10 SP 4.2]

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23. Solubility in a solvent is greater the farther a substance travels; thus the solubility decreases as C > B > A. Adsorption strength decreases with the distance moved so absorption decreases as A > B > C. Therefore, choice (A), which states that A is more soluble in the solvent than B, is not correct. Similarly, option (B), which says that B is more soluble in the solvent than C, cannot be correct. Choice (C), that B is adsorbed more strongly by the paper than C, is correct but choice (D), stating that B is adsorbed more strongly by the paper than A, is not correct.

The answer is (C).

[LO 2.10 SP 4.1]

24. The equation indicates a 10/2 or 5/1 mole ratio for Cl^-/MnO_4^-. Therefore, 0.0400 mol $Cl^- \times 2$ mol $MnO_4^-/10$ mol $Cl^- = 0.00800$ mol of MnO_4^-. Because the $[MnO_4^-]$ is 0.0200 *M*, the volume of $KMnO_4$ solution would equal 0.00800 mol $MnO_4^- \times 1$ L/0.0200 mol = 0.400 L, choice (D). Option (A) represents the number of mol of MnO_4^-. Option (B) gives moles but neglects the coefficient of 2 for MnO_4^-. Option (C) fails to multiply the *M* by two.

The answer is (D).

[LO 3.3 SP 2.2, 5.1]

25. To answer this question the moles of OH^- and H^+ must be calculated.
$0.0300\ L \times 0.100\ mol/L\ Ba(OH)_2 \times 2\ H^-/Ba(OH)_2 = 0.00600\ mol\ OH^-$
$0.0200\ L\ HNO_3 \times 0.200\ mol/L = 0.00400\ mol\ H^+$
Because OH^- and H^+ ions react in a 1/1 ratio, the difference between them will give the substance present in excess.
$0.00600\ mol\ OH^- - 0.00400\ mol\ H^+ = 0.00200\ mol\ OH^-$
The concentration of the excess substance is found by dividing the moles by the total volume, 0.0300 L + 0.0200 L.
$0.00200\ mol\ OH^-/0.0500 L = 0.040\ M\ OH^-$
Choice (A), with an excess of H^+, ignores the fact that there are two OH^- ions in each $Ba(OH)_2$ and fails to divide by the final V of 0.050 L. Choice (B), 0.020 *M* H^+, divides 0.001 mol H^+ by 0.050 L but fails to include the factor of two for OH^-. Option (C), 0.0020 *M* OH^-, uses the 2/1 stoichiometry factor for $OH^-/Ba(OH)_2$ but doesn't divide this value by 0.050 L.

The answer is (D).

[LO 3.3 SP 5.1]

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26. Molality is calculated by dividing the moles of solute by the kilograms of solvent.
3.00 g/60.0 g mol^{-1} = 0.0500 mol. 0.0500 mol/0.200 kg = 0.250 *m*, choice (C). Option (A), 0.0100, is the result of multiplying the moles of urea (0.050) by 0.20 kg rather than dividing them. Choice (B), 0.0500, is just the number of moles of solute and option (D), 10.0, is the result of multiplying the mass of urea (3.00 g) by the mass of H_2O (200.0 g) and dividing by the molar mass of urea (60.0 g).

The answer is (C).

[LO 3.4 SP 2.2, 5.1, 6.4]

27. The molality of a solution can be found from the freezing point depression and the freezing point depression constant with the equation $\Delta T = k_f m$. From the values given in the question, $-0.372/-1.86 = 0.200\ m$, choice (B). Result (A), 0.0200, is a decimal error. Choice (C), 0.500, results from dividing 1.86 by 0.372 and misplacing the decimal and option (D), 5.00, divides 1.86 by 0.372.

The answer is (B).

[LO 3.4 SP 2.2, 5.1, 6.4]

28. The molar mass of an unknown solute can be found from the freezing point depression of a solution in a two step process. First, the solution's molality is calculated from the freezing point depression and the fp depression constant. Then the moles of the solute are found from the molality and the number of kilograms of the solvent. The molar mass of the solute is obtained from the number of moles of solute and its measured mass.
$\Delta T = k_f m - 5.58/-1.86 = 3\ m$; 3 mol/kg × 0.0100 kg = 0.0300 mol solute
1.80 g/0.0300 mol = 60 g/mol, choice (B). Option (A), 54, comes from multiplying the molality, 3, by the mass of solute, 1.8, and by the mass of solvent in grams, 10. Choice (C), 180, is the result of dividing 1.80 g by 0.01 kg. and choice (D), 300, involves dividing 3 (the molality) by 0.010 (kg of H_2O).

The answer is (B).

[LO 3.4 SP 2.2, 5.1, 6.4]

29. The partial pressure of a gas can be found by multiplying the total pressure by the mol fraction.
$P_A = P_{total} \times \text{mol A}/(\text{mol A} + \text{mol B})$
56 g N_2/28g mol^{-1} = 2.0 mol; 32 g O_2/32 g mol^{-1} = 1.0 mol
P_{O_2} = 1.5 atm × 1.0 mol O_2/3.0 mol total = 0.50 atm, choice (B). Choice (A), 0.33 atm, is the mole fraction of O_2 (1.0/3.0). Choice (C), 0.55 atm, is the result of multiplying the total pressure by the mass fraction of O_2 (32/32 + 56) and choice (D), 1.0 atm, represents the partial pressure of N_2.

The answer is (B).

[LO 3.4 SP 2.2, 5.1, 6.4]

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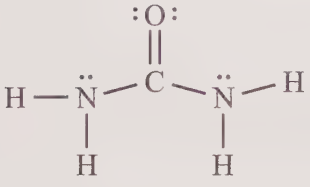
CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) The molarity of a solute is found by dividing the number of moles of solute by the number of liters of solution.
27 g urea/60 g mol^{-1} = 0.45 mol urea; 0.45 mol/0.025 L = 18 *M*

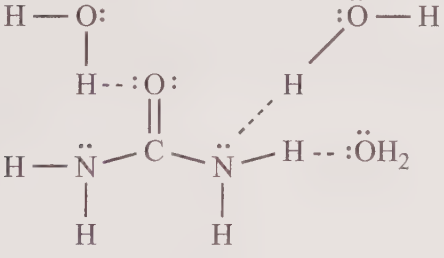
(b) The non-polar methoxyethane has a low solubility in polar H_2O because the non-polar solute molecules do not interact well with the polar solvent molecules. In contrast the polar $(H_2N)_2CO$ molecules can interact with polar H_2O molecules by means of hydrogen bonding.

[LO 2.13 SP 1.4]

(c)



(d) Three different interactions between urea and water are shown by the dotted lines.



[LO 2.8 SP 1.1, 1.2, 6.4]

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2. (a) Means to measure specified quantity of H_2SO_4 such as pipet or buret. Buret with which to dispense the NaOH.
Beaker or conical flask in which to mix the NaOH and H_2SO_4.
Means to signal equivalence point such as colored indicator or pH meter.

(b) The measurements that are needed are the volume of H_2SO_4 solution and the volume of NaOH solution needed to reach the equivalence point.

(c) Completion of reaction (equivalence point) is signaled by the change in color of an appropriate acid-base indicator or by a rapid change in pH if a meter is used.

(d) 23.50 is the average obtained from the first, third and fourth values. The second is omitted due to being too far away from the other three.

[LO 1.20 SP 4.2, 5.1]

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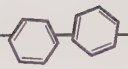

3. (a) The first equation is a precipitation reaction, because the reactants, Na_3PO_4 and $Ca(NO_3)_2$, are both soluble, but react to form insoluble $Ca_3(PO_4)_2$ and soluble $NaNO_3$.
The second equation includes both precipitation and acid-base processes. The acid, H_2SO_4, reacts with the base, $Ba(OH)_2$, to form H_2O and the insoluble $BaSO_4$.
The third reaction is an oxidation-reduction process, in which Cr (in $K_2Cr_2O_7$) undergoes reduction to form $CrCl_3$ while Sn (in $SnCl_2$) becomes oxidized to $SnCl_4$.

(b) $\mathbf{2}\ Na_3PO_4 + \mathbf{3}\ Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + \mathbf{6}\ NaNO_3$
$H_2SO_4 + Ba(OH)_2 \rightarrow BaSO_4 + \mathbf{2}\ H_2O$
$K_2Cr_2O_7 + \mathbf{3}\ SnCl_2 + \mathbf{14}\ HCl \rightarrow \mathbf{2}\ CrCl_3 + \mathbf{3}\ SnCl_4 + \mathbf{7}\ H_2O + \mathbf{2}\ KCl$

(c) i. $Ba(OH)_2$
ii. $K_2Cr_2O_7$, 6 electrons gained
iii. eqn. 1 $Ca_3(PO_4)_2$
eqn. 2 $BaSO_4$

[LO 3.2 SP 1.5, 7.1] [LO 3.7 SP 6.1] [LO 3.8 SP 6.1]

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CHAPTER 6
STOICHIOMETRY

1. Each formula contains one S (Cs_2S, Li_2S, K_2S, MgS) so look for the lightest relative mass of metal, leaving the heaviest relative mass of sulfur and therefore the greatest mass percent. Cesium, potassium, and magnesium all have much larger atomic masses than lithium. Lithium contributes by far the lightest mass even though there are two lithium atoms for every sulfur atom.

   The correct answer is (B).

   [LO 3.5 SP 2.1, 4.2]

2. Methanoic acid (molar mass 46) contains only one carbon atom so the mass percent of carbon is $12/46 \times 100\%$. The other answers are the relative mass of hydrogen (2/46) and oxygen (16/46 but should be 32/46) in (B) and (C) respectively. In (D) the mass of one oxygen is left out of the total mass.

   The correct answer is (B).

   [LO 3.5 SP 2.1, 4.2]

3. MnO is 55/71 metal mass; MnO_2 is 55/87; and Mn_2O_3 is 110/158. Each is comfortably above 50% mass manganese.

   The correct answer is (D).

   [LO 3.5 SP 2.1, 4.2]

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4. The net ionic equation for formation of the precipitate is

$$Ni^{2+}(aq) + CO_3^{2-}(aq) \rightarrow NiCO_3(s)$$

There are 1.2 moles of Ni^{2+} but only 0.40 moles of CO_3^{2-} so almost 0.40 moles of $NiCO_3$ precipitate forms. There are 0.8 moles Ni^{2+} left in excess. Choice (A) selects the wrong excess ion. Choice (C) gives the correct color of the precipitate but incorrectly assumes that the reacting ions are in the correct stoichiometric ratio. Choice (D) must refer to some other reaction where one finds a one-to-three ratio between the cation and anions, clearly not the case here.

The correct answer is (B).

[LO 3.4 SP 2.2, 5.1, 6.4]

5. For each member of a pair of answers, multiple the number of moles by the number of oxygen atoms in the formula to find the total number of moles of oxygen atoms. In choice (A), this yields 0.30 moles and 0.50 moles of oxygen respectively, clearly not the same. In choice (B), Br_2O and HBrO each contain one oxygen atom in the formula and there are 0.20 moles of each, so the number of moles of oxygen atoms is the same. Each of the other sets changes the number of moles and/or the subscript for oxygen in the formula so the number of moles of oxygen is not the same. Choice (C) shows 0.10 moles and 0.40 moles of oxygen atoms respectively, while choice (D) yields 0.40 and 0.80 moles.

The correct answer is (B).

[LO 3.4 SP 2.2, 5.1, 6.4]

6. Multiply molarity times volume times subscript of ion to find the number of moles of each ion: phosphate 0.20 moles; manganese(II) 0.80 moles; potassium cation 0.60 moles; nitrate 1.6 moles. The phosphate anion is limiting so its concentration is essentially zero after the reaction occurs. Manganese(II) changes by 0.30 moles to leave 0.50 moles. Potassium cation and nitrate anion are spectator ions so their concentrations are not changed by reaction, just by dilution.

The correct answer is (A).

[LO 3.4 SP 2.2, 5.1, 6.4]

7. The molar mass of calcium carbonate is just over 100 grams per mole so the starting mass represents half a mole of calcium carbonate. Therefore half a mole of calcium carbide is expected, or half of 64 grams equals 32 g. 75% of that is 24 g. The correct answer is (C). Choice (A) is the initial mass of calcium carbonate. Choice (B) is the theoretical yield of calcium carbide. Choice (D) is close to the theoretical yield of carbon monoxide.

The correct answer is (C).

[LO 3.3 SP 2.2, 5.1]

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8. The atomic mass of aluminium is just less than 27 grams per mole. Since 54 g Al is a bit over 2 moles and 1 mole of gas at STP is 22.4 L, the remaining factor is the stoichiometric ratio of 3 moles O_2:2 moles Al. That requires multiplication by 3/2, or $1.5 \times 2 \times 22.4$ L.

   The correct answer is (A).

   [LO 3.4 SP 2.2, 5.1, 6.4]

9. The equal mass of nitrogen in each compound suggests an equal number of moles. The greatest number of oxygen atoms also corresponds to the greatest number of moles. So look for the highest ratio of N:O among the formulas. Choice (A) NO is 1:1; Choice (B) N_2O_3 is 1:1.5; choice (C) NO_2 is 1:2; and finally N_2O_5 represents a 1:2.5 ratio of nitrogen to oxygen.

   The correct answer is (D).

   [LO 3.6 SP 2.2, 6.1]

10. Since volume and temperature are constant, the total pressure in the container is proportional to the total number of moles of gas and to the number of volumes of gas, according to Avogadro's Law of Combining Volumes. After the reaction, the limiting reactant ethane is completely consumed. Remaining in the flask is the excess reactant (3 L oxygen) and the gaseous products, including 4 L carbon dioxide and 6 L water vapor. Thus the volumes of gas increase from 12 L initially to 13 L after the reaction, so the total pressure increases by 13/12. The correct answer is (C). Choice (A) miscounts the total number of moles (and volumes) of gases. Choice (B) inverts the ratio of change. Choice (D) misidentifies the number of moles (or volumes) of gases.

    The correct choice is (C).

    [LO 3.4 SP 2.2, 5.1, 6.4]

11. When the equation is balanced using smallest whole number coefficients, the correct coefficients are 2, 3, 2, 3 respectively. There are 17 ions on the reactant side which are rearranged to form one precipitate and several spectator ions. There are 41 atoms on the reactant side, same as the product side. The correct answer is (A). Choice (B) miscounts the number of ions while choice (C) miscounts the number of atoms. Choice (D) miscounts the number and charge of ions remaining in solution.

    The correct answer is (A).

    [LO 3.1 SP 1.5, 7.1]

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12. One way to consider this problem is to create the ratio of moles of vanadium per one mole of oxygen (for choice (A) VO, 1:1; for choice (B) V_2O_3, 0.67:1; for choice (C) VO_2, 0.5:1; and for choice (D) V_2O_5, 0.4:1). The combination with the greatest number of moles of vanadium per mole of oxygen will also have the greatest mass percent of the metal.

    The correct answer is (A).

    [LO 3.4 SP 2.2, 5.1, 6.4]

13. Since the precipitation reaction is described by the net ionic equation $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$, there must be the same number of moles of barium cation and sulfate anion. Volume (in liters) times molarity equals the number of moles. Therefore (0.040 L)(0.250 *M*) barium cation = (0.050 L)(0.200 *M*) sulfate anion.

    The correct answer is (B).

    [LO 3.3 SP 2.2, 5.1]

14. The balanced equation (coefficients 1, 5, 3, 4 respectively) shows a 1:5 mol ratio of C_3H_8 to O_2 and 11.2 L C_3H_8 is equivalent to 0.5 moles, so 5×0.5 mol = 2.5 mol.

    The correct answer is (C).

    [LO 3.4 SP 2.2, 5.1, 6.4]

15. Since barium hydroxide has two hydroxides per formula unit, the number of moles of hydroxide is $2 \times 0.025\ L \times 0.0100\ M = 0.0005$ moles OH^-. For the hydrochloric acid solution, $0.020\ L \times 0.0250\ M = 0.0005$ moles H^+. The number of moles of OH^- and H^+ must be the same since those ions combine to form water.

    The correct answer is (B).

    [LO 3.4 SP 2.2, 5.1, 6.4]

16. The balanced equation shows a 1:2 ratio of moles CH_4 to moles O_2. 32 g CH_4 is equivalent to 2 moles while 32 g O_2 is one mole, so O_2 is limiting and 0.5 mole CH_4 are consumed, leaving 1.5 mole CH_4 in excess.

    The correct answer is (B).

    [LO 3.4 SP 2.2, 5.1, 6.4]

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17. Since nitrate anion is not involved in the precipitation, all of it remains in solution. The solution volume has doubled so 0.050 mole NO_3^-/0.200 L = 0.25 *M*.

The correct answer is (C).

[LO 3.3 SP 2.2, 5.1]

18. Since 0.025 mole of each ion exist and they react in a 1:1 ratio, a total of 0.025 mole of precipitate is formed.

The correct answer is (B).

[LO 3.3 SP 2.2, 5.1]

19. The system volume is increased to a total of 200 mL. Since the number of moles of each spectator ion remains the same but the volume doubles, the concentration of each is halved.

The correct answer is (B).

[LO 3.3 SP 2.2, 5.1]

20. If the reaction is limited by 0.15 mole of magnesium, then 0.15 mole of MgO would be produced since the reactant and product react in a 2:2 ratio. The product of 0.15 mole MgO (molar mass 40.3) is about 6 g.

The correct answer is (C).

[LO 3.4 SP 2.2, 5.1, 6.4]

21. The reactant 0.50 mole of ZnS becomes 0.50 mole of ZnO, then in the subsequent equation 0.50 mole of Zn. In the second equation, 0.50 mole of C are used in the process so there are 0.50 mole C in excess. So the crucible would contain 0.50 mole of Zn (about 32 g) and 0.50 mole of C (about 6 g) for a total mass of 40 g.

The correct answer is (B).

[LO 3.3 SP2.2, 5.1]

22. Beryllium oxide, BeO, is 16/25 oxygen, or 64%. The other oxides are all smaller fractions of oxygen (choice (B) Li_2O 16/30; choice (C) MgO 16/40; choice (D) Na_2O 16/62).

The correct answer is (A).

[LO 3.4 SP 2.2, 5.1, 6.4]

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23. The molar volume of any gas at STP is 22.4 L. Since decomposition of one mole of sodium perchlorate leads to two moles oxygen gas, the total volume of oxygen gas produced is twice 22.4 or 44.8 L.

    The correct answer is (D).

    [LO 3.4 SP 2.2, 5.1, 6.4]

24. The original solution contains $2 \times 0.20\ M \times 1.00\ \text{L} = 0.40$ mole Cl^- anion. Thus 0.60 mole of Cl^- must be added (or 0.30 mol $CaCl_2$) to total one mole of Cl^- anion.

    The correct answer is (B).

    [LO 3.4 SP 2.2, 5.1, 6.4]

25. The percent mass of copper is (63.55/250) or approximately 25%, the sulfur (32.07/250) or about 13%, the oxygen from the sulfate 64/250) or about 26%, and the water $(5 \times 18)/250$ or 36%.

    The correct answer is (D).

    [LO 3.4 SP 2.2, 5.1, 6.4]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) 4.775 g total = (1.909 g C + 0.6080 g H + 2.258 g N). Convert each to moles by dividing each by its respective atomic mass: (1.909/12.01) = 0.1590 mole of C; (0.6080/1.01) = 0.6020 mole of H; and (2.258 /14.01) = 0.1612 mole of N. Then divide each molar quantity by the smallest one (0.1590 moles of C) to find the ratio of 1 C to 4 H to 1 N. Thus the likely formula is $NHCH_3$.

[LO 3.6 SP 2.2, 6.1]

(b) Rearrange the Ideal Gas Equation to isolate the molar mass of the gas: MM = gRT/PV = (26.83g) (0.08205 L atm/mol K)(273 K)/ (1 atm)(10.0 L) = 60.10 g/mol

[LO 3.6 SP 2.2, 6.1]

(c) To find the molecular equation, divide the molar mass by the empirical mass, so MM/empirical formula mass = 60.10/30.06 = 2 ; then

$$2 \times NHCH_3 = N_2H_2 (CH_3)_2$$

[LO 3.6 SP 2.2, 6.1]

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2. (a) The balanced equation is $4\,PH_3(g) + 8\,O_2(g) \rightarrow P_4O_{10}(s) + 6\,H_2O(g)$

[LO 3.2 SP 1.5, 7.1]

(b) Straightforward stoichiometry shows that 1.25 mol
$PH_3 \times (1\text{ mol } P_4/4\text{ mol } PH_3) \times (283.88\text{ g } P_4O_{10}/1\text{ mol } P_4O_{10}) = 88.7\text{ g } P_4O_{10}$

[LO 3.3 SP 2.2, 5.1]

(c) $10.0\text{ L } PH_3 \times (6\text{ L } H_2\text{ O}/4\text{ L } PH_3) = 15.0\text{ L } H_2O$

[LO 3.3 SP 2.2, 5.1]

(d) After the reaction is completed, the following quantities remain:
$0\text{ mol } O_2 + 0.173\text{ mol } PH_3 + 0.293\text{ mol } H_2O = 0.466\text{ mol gases total;}$
$P = nRT/V = (0.466\text{ mol})(0.08205\text{ L atm/molK})(398\text{ K})/(10\text{ L}) = 1.52\text{ atm}$

[LO 3.4 SP 2.2, 5.1, 6.4]

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3. (a) $2\,H^+(aq) + 3\,H_2C_2O_4(aq) + 2\,MnO_4^-(aq) \rightarrow 6\,CO_2(g) + 2\,MnO_2(s) + 4\,H_2O(l)$

[LO 3.8 SP 6.1]

(b) $[+7, +4]$

[LO 3.8 SP 6.1]

(c) $0.0300\text{ L} \times 0.200\ M = 0.006\text{ mol } MnO_4^-$
$0.006\text{ mol } MnO_4^- \times (3\text{ mol } H_2C_2O_4 / 2\text{ mol } MnO_4^-) = 0.009\text{ mol } H_2C_2O_4$
$(0.009\text{ mol } H_2C_2O_4 / 0.0265\text{ L}) = 0.340\ M\ H_2C_2O_4$

[LO 3.9 SP 4.2, 5.1]

(d) $0.009\text{ mol } H_2C_2O_4 \times (2\text{ mol } MnO_2 / 3\text{ mol } H_2C_2O_4) \times (86.94\text{ g } MnO_2 / 1\text{ mol } MnO_2)$
$= 0.522\text{ g } MnO_2$

[LO 3.9 SP 4.2, 5.1]

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CHAPTER 7

CHEMICAL KINETICS

1. Represents the ΔH of the forward reaction ΔH is calculated by Products- Reactants. The correct answer is interval CD.

   The correct answer is (B).

2. Activation energy, E_a, is the minimum energy which must be supplied to the reactants to form the activated complex. This is interval AB.

   The correct answer is (A).

3. A catalyst does not alter ΔH, because the reactants and the product outcomes are the same, by the definition of a catalyst.

   The correct answer is (B).

4. The E_a for the reverse reaction is the minimum energy absorbed by the products to form the activated complex. This is interval DE.

   The correct answer is (C).

   [LO 4.5 SP 6.2, Esk 4.B.2] [LO 4.6 SP 1.4, 6.4 Esk 4.B.3] [LO 4.8 SP 1.5 EsK 4.D.1]

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5. The study of altering reaction rates by changing mechanisms and energy pathways is called catalysis. Catalysts are the substances which can change a reaction mechanism by altering the reaction pathway with a different energy requirement.

   The correct answer is (B).

   [LO 4.8 SP 1.5, EsK 4.D.1]

6. H• + •F represent unstable intermediates with an unpaired electron. The two atoms go on to form a stable molecule, HF with a single, covalent bond. Therefore, this w reaction would be classified as a chain-terminating step; no new intermediates are generated.

   The correct answer is (C).

   [LO 4.5 SP 6.2, EsK 4.B.2] [LO 5.3 SP 7.1, EsK 5.A.2]

7. The number of molecules that have the necessary activation energy increases. Changing temperature from 20°C to 30°C. become 293k and 303 k in Kelvin scale. $303/293 = 1.03$ increase in kinetic energy, so the ratio of the increase in velocity of the molecules ($\sqrt{1.03}$) is less than a 2% increase and does not account for the substantial increase.

   The correct answer is (D).

   [LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

8. As there are fewer reactant particles remaining available for collisions, the collision frequency drops, and so the rate at which product particles are formed per minute decreases.

   The correct answer is (C).

   [LO 3.3 SP 2.2, 5.1 EsK 3] [LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

9. The number of molecules of A decreases. This is false because A is a product in the reaction and the number of molecules of A increases as reactants successfully collide. As the reaction proceeds, the system starts with 2 moles of reactant gas and ends up with 3 moles of product gases, causing the final pressure to be greater.

   The correct answer is (B).

   [LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

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10. If 0.50 *M* B remain, 0.5 *M* B reacts, 0.5 *M* B × 2A/1 B = 1.0 *M* A reacts. 3.0*M* A − 1.0*M* = 2.0 *M* A remains.

    The correct answer is (A).

    [LO 3.3 SP 2.2, 5.1 EsK 3] [LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

11. $\frac{\text{Rate}}{[\text{A}][\text{B}]} = \text{k} = \frac{0.36 \text{ mol L}^{-1} \text{ sec}^{-1}}{(3.0\ M)(1.0\ M)} = 0.12\ M^{-1} \text{ sec}^{-1}$

    The correct answer is (B).

    [LO 4.1 SP 4.2, 5.1 EsK 4.A.1] [LO 4.4 SP 7.1, EsK 4.B.1, 4.A.3, 4.B.2]

12. $\text{mol}^{-1}\text{L sec}^{-1}$ See mathematical operation in #11. One M top and bottom cancel out, leaving one M in the bottom per sec. This can be written as $\text{M}^{-1} \text{ sec}^{-1}$.

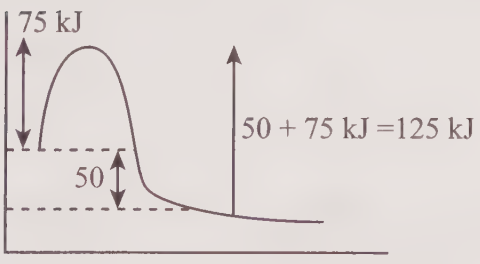
    The correct answer is (B).

    [LO 4.1 SP 4.2, 5.1 EsK 4.A.1] [LO 4.4 SP 7.1, EsK 4.B.1, 4.A.3, 4.B.2]

13. The stoichiometry between A and C is 1:1, so every time 1 molecule of A successfully reacts, one molecule of C forms. The rate at which [C] forms is equal to the rate at which [A] decreases.

    The correct answer is (C).

    [LO 4.1 SP 4.2, 5.1 EsK 4.A.1] [LO 3.3 SP 2.2,5.1 EsK 3]

14. 

    The correct answer is (D).

    [LO 4.6 SP 1.4, 6.4 EsK 4.B.3]

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15. With zero order of B, B is not involved in the rate-controlling (slowest) step. Only 2 molecules of A appear in the rate law.

The correct answer is (C).

[LO 4.5 SP 6.2, EsK 4.B.2

16. The overall output is determined by the slowest step in the mechanism. In this case, the smallest funnel determines the flow rate 2 mL/sec.

The correct answer is (A).

[LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

17. Regardless of the location of the funnel, the smallest funnel still controls the overall flow rate. "A chain is only as strong as its weakest link," regardless of placement of that link

The correct answer is (A).

[LO 4.1 SP 4.2, 5.1 EsK 4.A.1] [LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

18. If the rate law = $k[N_2]^1[H_2]^2$ and the concentrations of both reactants double, then $2^1 \times 2^2 = 8 \times$ larger rate.

The correct answer is (C).

[LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

19. Once the rate law for one ingredient is known, the rate law for other ingredients can be determined from the stoichiometry of the reaction. rate = $k[N_2]^1[H_2]^2$ for $NH_3 \times (3\ H_2/2\ NH_3) = 3/2\ k[N_2]^1[H_2]^2$

The correct answer is (B).

[LO 4.4 SP 7.1 EsK 4.B.1]

20. Time and rate are inversely related. As the time increases, rate slows down and vice versa. Inverse relationships take the shape of graph A.

The correct answer is (A).

[LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

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21. Increasing or decreasing temperature does not alter activation energy. It merely changes the number of reactant particles that possess the needed activation energy for a reaction.

    The correct choice is (D).

    [LO 4.6 SP 1.4, 6.4 EsK 4.B.3]

22. In reactions where a reactant is not zero order, increasing concentration increases collision frequency, which in turn increases the number of products formed/minute. The greater the concentration, the greater the reaction rate. A direct relationship is depicted on graph (C).

    The correct choice is (C).

    [LO 4.1 SP 4.2, 5.1 EsK 4.A.1]

23. Please see Chapter 7 Summary chart 7.2 for a zero order graph.

    The correct answer is (D).

    [LO 4.2 SP 5.1 EsK 4.A.2, 4.A.3] [LO 4.4 SP 7.1 EsK 4.B.1, 4.A.3, 4.B.2]

24. Please see Ch.7 Summary chart 7.2 for a second order graph.

    The correct answer is (A).

    [LO 4.2 SP 5.1 EsK 4.A.2, 4.A.3] [LO 4.4 SP 7.1 EsK 4.B.1, 4.A.3, 4.B.2]

25. When the amount of Y is held constant (in trials one and three), and the concentration of X_2 doubles, the reaction rate (in the last column) also doubles. Therefore X_2 is is first order.

    The correct answer is (B).

    [LO 4.2 SP 5.1 EsK 4.A.2, 4.3]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) II and VI only. These steps produce unstable atoms which must proceed to react further to form stable, bonded molecules. Step I is referred to as the "chain-initiating" step in the reaction.

   (b) III, IV and V only. These steps result in the formation of (only) stable molecules.

   [LO 4.1 SP 4.2, 5.1, EsK 4.A.1] [LO 4.4 SP 7.1 EsK 4.A.3, 4.B.2] [LO 6.1 SP 6.2, EsK 6.A.1]

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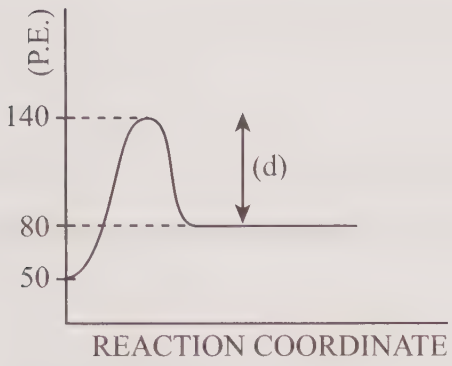
2.



(a) An endothermic diagram is required, beginning at 50 kJ/mol, peaking at 140 kJ/mol for the activation energy, and ending up 30 kJ/mol higher, at 80 kJ/mol for the products.

(b) For the reverse reaction, the roles of products and reactants are reversed, so the ΔH has the same numerical difference between them, but with the opposite sign: 50 kJ/mol − 80 kJ/mol = −30 kJ/mol

(c) The reactants start at 50 kJ/mol and the activation energy tells us that the reactants absorb 90 kJ/mol to form the activated complex. 50 kJ/mol of the reactants + 90 kJ/mol absorbed = 140 kJ/mol

(d) The products end up with a P.E. of 80 kJ/mol (50 kJ/mol + 30 kJ/mol as the ΔH), making the energy needed to form the reaction intermediate in the reverse reaction as the difference between 80 kJ/mol → 140 kJ/mol = 60 kJ/mol

[LO 4.6 SP 1.4, 6.4 EsK 4.B.3] [LO 4.7 SP 6.5, EsK 4.C.1, 4.C.2, 4.C.3]

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3. (a) Reactant R is first order. In trials 5 and 6, with Z_2 held fixed, when the pressure of R doubles, the rate also doubles.

   (b) In trials 1 and 2, or 2 and 3, when the pressure of R is held constant and the pressure of Z_2 doubles, the rate increases by a factor of $4(2^2)$. Combining answers from A and B, the rate law is $\text{Rate} = k[R]^1[Z_2]^2 \rightarrow \text{Rate} = k[R][Z_2]^2$

   (c) Using the data in Trial 1. $k = \dfrac{6.25 \text{ mm Hg sec}^{-1}}{400 \text{ mm Hg} \times (76 \text{ mm Hg})^2} = 2.7 \times 10^{-6} (\text{mmHg}^{-2}) \text{ sec}^{-1}$

   (d) The easiest approach is to view trials 5 and 7. R is held constant and the pressure of Z_2, the second order reactant, is halved. $(1/2)^2 = 1/4$ the original rate in trial $5 = 1/4\,(110) = 27.5$. mm Hg sec^{-1}

   (e) Z_2 = a second-order reactant, and referring to the summary chart 7.2 in the Chapter 7 information, graph A is the correct answer.

[LO 4.1 SP 4.2, 5.1 EsK 4.A1] [LO 4.2, SP 5.1 EsK 4.A.2, 4.A.3] [LO 4.3 SP 2.2, 2.2 EsK 4.A.3]

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4. (a) Graphs (B) and (E) both represent exothermic reactions, but Graph (B) has the higher E_a.

   (b) Although the skin of the human body is warm to the touch and radiates heat, partly due to the internal temperature of the body which is maintained at approximately 98.6°F, in order for the reactions and internal body temperature to be maintained, there must be a continual intake of energy (food). That means the sum of the net process is an endothermic system. Graph (A) is the best representation of an endothermic system.

[LO 4.7 SP 6.5, EsK 4.C.1, 4.C.2, 4.C.3] [LO 4.6 SP 1.4, 6.4 Esk 4.B.3] [LO 6.1 SP 6.2 EsK 6.A.1]

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CHAPTER 8

CHEMICAL EQUILIBRIUM

1. Choice (A) includes all the components, solid as well as gases and multiplies the $[NH_3]$ by 2 rather than raising it to the second power. Choice (B) squares the $[NH_3]$ and multiplies it by the $[CO_2]$ but incorrectly includes the concentration of the solid NH_2COONH_4. Option (C) omits the solid but multiplies the $[NH_3]$ by 2 rather than raising it to the second power. In (D), $NH_2COONH_4(s)$ is not included in the equilibrium expression and $[NH_3]$ is squared because of its coefficient of 2 in the equation.

   The correct answer is (D).

   [LO 6.4, 6.5 SP 2.2]

2. The identity of solids and/or liquids might not be evident from an equilibrium expression because these substances are not included in these expressions. There should be no difficulty distinguishing among reactants and products (choice B) because reactants appear in the denominator and products are in the numerator of the equilibrium expression. The extent of the reaction is not needed for the K expression or the equation (choice C). The coefficients in the equation are equal to the exponents in the K expression (choice D).

   The correct answer is (A).

   [LO 6.4, 6.5 SP 2.2]

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3. In this question the original equation has been reversed and divided by two. When an equation is reversed, the K expression has to be inverted. When an equation is multiplied or divided, the original K is raised to the corresponding power. The K for the new equation will be the inverse of K_1 raised to the $1/2$ power. Option (A) is divided by two and not inverted. Option (B) is inverted but not raised to the proper power $-1/2$. Option (D) is raised to the $1/2$ power, but is not inverted. Option (C) shows the inverse of K_1 raised to the $1/2$ power.

   The correct answer is (C).

   [LO 6.2 SP 2.2]

4. In order to obtain the equation of interest from the equations represented by K_1 and K_2, reaction 1 must be doubled so that 2 NO is canceled when it is added to equation 2. Therefore, K_1 must be squared then multiplied by K_2. In choice (A) the two K values are added to one another. In choice (B), K_1 is squared but added to K_2. In option (C), the product of K_1 and K_2 is multiplied by 2. In choice (D), K_1 is squared and multiplied by K_2.

   The correct answer is (D).

   [LO 6.2 SP 2.2]

5. Beginning with just reactants the initial rate of the forward reaction of any reaction is greater than that for the reverse reaction as indicated in choices (A) and (B). In choice (C), the rates of the forward and reverse reactions are equal, and in choice (D), the initial rate of the forward reaction is less than that of the reverse reaction. If the two rates were equal as in choice (C), the reaction would not move forward and if the reverse rate were faster than the forward rate, the reaction would proceed backwards. Based on the initial rates, the choices are either (A) or (B) and the decision as to which is correct depends on the rates at equilibrium. Choice (A) cannot be correct because the rate for the forward reaction is greater than that for the reverse reaction, and the reaction would continue to proceed. However, in option (B), the rates of the forward and reverse reactions are equal, which is the definition of equilibrium.

   The correct answer is (B).

   [LO 6.3 SP 7.2]

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6. In order to determine the direction that a reaction containing reactants and products will proceed the value of the reaction quotient, Q, which has the same form as the equilibrium constant, must be found. In this case, $Q = [N_2O_4]/[NO_2]^2 = 1.5/(0.50)^2 = 1.50/0.25 = 6$. Because the value of Q is larger than K, the reaction will shift toward reactants (NO_2). In choice (A), the value of Q (1.5) is the result of doubling (not squaring) the $[NO_2]$, and in choice (B) the incorrect value of Q is found by dividing the $[N_2O_4]$ by that of $[NO_2]$. Option (D) would be true only if Q were equal to K, which could not occur with these concentrations. This question shows the importance of using the proper form of Q when doing such calculations.

The correct answer is (C).

[LO 6.4 SP 2.20]

7. K_c is calculated from the equilibrium concentrations of the reactants and products. The initial $[ICl] = 0.10\ M$. To find the equilibrium concentrations one can set up a table.

	[ICl]	$[I_2]$	$[Cl_2]$
Initial	0.10		
Change			
Equilibrium	0.060		

With the initial and equilibrium concentrations of ICl, the rest of the table can be filled in. Because the [ICl] decreased from 0.10 to 0.060 M, it decreased by 0.040.

From the 2:1 stoichiometry in the equation the 0.040 M decrease in [ICl] will lead to the formation of 0.020 M for $[I_2]$ and $[Cl_2]$, which will also be the equilibrium concentrations of these substances.

	[ICl]	$[I_2]$	$[Cl_2]$
Initial	0.10	0	0
Change	–0.040	+0.020	+0.020
Equilibrium	0.060	0.020	0.020

The equilibrium values can be substituted into the equilibrium constant expression $K = [I_2][Cl_2]/[ICl]^2$ to give $K = [0.020][0.020]/[0.060]^2$. This expression can be simplified to $K = (1/3)^2$. Thus, $K = 1/9$ or 0.11 option (A). Choice (B) results from not squaring 1/3. Choice (C) is the result of squaring the concentrations that result from not taking the 2:1 stoichiometry into account, while option (D) is obtained by dividing the concentrations obtained by ignoring 2:1 stoichometry without squaring them.

The correct answer is (A).

[LO 6.5 SP 2.2]

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8. $MgCO_3$ ionizes to give Mg^{2+} and CO_3^{2-} If the solubility of $MgCO_3$ is s, the $[Mg^{2+}] = [CO^{2-}] =$ s. The $K_{sp} = [Mg^{2+}][CO_3^{2-}] = s \times s$ or s^2. Choice (A), 2s, would be the result of adding the solubilities of the two ions rather than multiplying them. Choice (C), $4s^2$, would result if the concentration of one of the ions were doubled and multiplied by the concentration of the other while option (D), $4s^3$ is the K_{sp} formula for a1:2 or 2:1 salt.

The correct answer is (B).

[LO 6.6 SP 2.2]

9. Ag_2CO_3 ionizes to give two Ag^+ and CO_3^{2-} ions. The solubility of Ag_2CO_3 is S so the $[Ag^+]$ will be 2S and the $[CO_3^{2-}]$ will be S. When these values are substituted into the K_{sp} expression, $K_{sp} = [Ag^+]^2 [CO_3^{2-}]$, the result is $K_{sp} = (2S^2)(S) = 4S^3$. Alternative (A), 2S, represents the $[Ag^+]$. Selection (B), would be the square of the $[Ag^+]$ if it were not doubled. Choice (C), $4S^2$, is either the square of the $[Ag^+]$ or the $[Ag^+]$ times the $[CO_3^{2-}]$. Option (D), $4S^3$, results when the $[Ag^+]$, 2S, is squared and multiplied by the $[CO_3^{2-}]$ which equals S.

The answer is (D).

[LO 6.6 SP 2.2]

10. The large value of K means that the products will be greatly favored over the reactants. Because they are reactants, alternatives (A), $CO_2(g)$, and (B), $H_2(g)$, will have lower concentrations than the products, $CH_4(g)$, option (C) and $H_2O(g)$, choice (D). According to the stoichiometry of the reaction, $H_2O(g)$, option (C), will be twice as abundant as $CH_4(g)$, choice (D).

The correct choice is (D).

[LO 6.7 SP 2.3]

11. Several of the factors listed may change the position of the equilibrium, but temperature is the only factor that can change the value of K. Adding a solid such as $C(s)$, option (A), affects neither the position of equilibrium nor the equilibrium constant K. Compressing the container, choice (C), will cause the system to shift toward the smaller volume but will not affect the value of the equilibrium constant, K. Adding a chemical such as $H_2O(g)$ in alternative (D), will push the equilibrium position toward the opposite side, but will not affect the value of K.

The correct answer is (B).

[LO 6.8 SP 6.4]

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12. As stated in the answer to question 11, adding C(*s*), choice (A), will not affect the position of the equilibrium, so it cannot influence the quantity of $H_2(g)$. The reaction is endothermic ($\Delta H = 131$ kJ/mol), so increasing the temperature, option (B), will shift the equilibrium position to the right and, thus, increase the quantity of $H_2(g)$. However, changing the temperature will also change the value of the equilibrium constant, *K*. Compressing the container, choice (C), will shift the equilibrium position toward the reactants which have fewer moles of gas. Adding $H_2O(g)$, selection (D), will shift the reaction position to the right, increasing the quantity of $H_2(g)$ without affecting the value of the equilibrium constant, *K*.

    The correct answer is (D).

    [LO 6.8 SP 6.4]

13. As stated in the answers to questions 11 and 12, adding a solid, alternative (A), has no effect on the position of equilibrium. Because the reaction as written is endothermic, increasing the temperature, selection (B), will shift the equilibrium toward the products. Compressing the container, alternative (C), will shift it toward the reactants, because there are fewer moles of gas in the reactants. Adding $H_2O(g)$, a reactant, will shift the equilibrium position toward the products.

    The correct answer is (A).

    [LO 6.8 SP 6.4]

14. The quantity of $H_2(g)$ will be decreased when the equilibrium position is shifted toward the reactants. Adding C(s), option (A), has no effect on the equilibrium position. Increasing the temperature, alternative (B), will shift the equilibrium position of this endothermic reaction toward the products, increasing the quantity of $H_2(g)$. Compressing the container, choice (C), will shift the equilibrium to conditions that will offset the increased pressure, i.e. toward the reactants, which will result in a decrease in the quantity of $H_2(g)$. Adding the reactant $H_2O(g)$, alternative (D), will promote a shift toward the products, increasing the quantity of $H_2(g)$.

    The correct answer is (C).

    [LO 6.8 SP 6.4]

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15. With 5 moles of gaseous reactants and 3 moles of gaseous products, more $CH_4(g)$ will be formed at high P, options (A) or (B). Because the reaction is exothermic ($\Delta H^\circ = -165$ kJ/mol), the products will be favored by a low T, alternatives (B) or (D). Selection (A), high P and high T, would increase the yield of a product for an endothermic reaction with more moles of gaseous reactants than products. Choice (C), low P and high T, would increase the yield of a product in an endothermic process with more gaseous products than reactants. Option (D), low P and low T, would favor the products for an exothermic reaction in which the moles of gaseous products exceed the moles of gaseous reactants.

The correct answer is (B).

[LO 6.9 SP 4.2]

16. The diagram shows one of ten molecules in the form of ions. As a strong acid, HCl, selection (A), would have all of the molecules in ionic form with none in molecular form. For alternative (B), HOClO ($K_a = 0.01$), a 1 *M* solution would give $[H^+] = [A^-] = 0.10$, or 1/10 ionization. Choice (C), $HC_2H_3O_2$, with a $K = 1.8 \times 10^{-5}$, would ionize to 0.4%. This would represent 4 ionized molecules out of 1000, far fewer than shown in this diagram. In HOCl ($K_a = 2.9 \times 10^{-8}$), option (D), about 1 molecule in every 10,000 will ionize.

The correct answer is (B).

[LO 6.11 SP 1.4]

17. The initial pH is 1 for a 1 *M* strong acid since strong acids ionize completely. The pH of a 1 *M* solution of an acid with $K \sim 1 \times 10^{-5}$ is about 2.4. This is obtained from $1.8 \times 10^{-5} = [H^+]^2/1$ from which $[H^+] = 4.24 \times 10^{-3}$ and $-\log[H^+] = 2.37$. Thus, choice (A), that the initial pH values are the same, cannot be correct. The pH = 7 at the equivalence point of a strong acid - strong base titration. For the titration of a weak acid with a strong base, the pH will be higher than 7 at the equivalence point because the anion formed from the weak acid will undergo hydrolysis (react with H_2O) to form OH^- ions and unionized HA. (The weaker the acid is the higher its pH at the equivalence point will be.) From the discussion about alternative (A) above, the percentage ionization of strong and weak acids will be different, so option (C) cannot be correct. The volume of 1.0 *M* NaOH needed to reach the equivalence point for titrations of equal volumes of weak and strong acids is the same, because the number of moles of acid is the same in each case (volume in L $\times$ *M*).

The correct answer is (D).

[LO 6.12 SP 1.4]

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18. $K_w = [H^+][OH^-]$ $K_w^{1/2} = [H^+] = [OH^-]$ for pure water at all temperatures even though K_w increases with increasing temperature. Because $[H^+] = [OH^-]$ in pure water it becomes neither more acidic, choice (A), nor more alkaline, option (C). $[H^+] = K_w^{1/2}$ and $pH = -\log[H^+]$. Because K_w increases with increasing temperature, $[H^+]$ will also increase and the pH will decrease, selection (B). Because K increases with increasing temperature, ΔH°_{ioniz} must be endothermic not exothermic as stated in alternative (D).

The correct answer is (B).

[LO 6.14 SP 6.2]

19. pH = 4.0 so $[H^+] = 1.0 \times 10^{-4}$. For a pure monoprotic acid $[H^+] = [A^-]$ and $K_a = [H^+][A^-]/[HA]$. Thus, $K = (1.0 \times 10^{-4})^2/0.50 = 2.0 \times 10^{-8}$. The strong acid HBr, choice (A), will ionize completely so will have a K_a that is much larger than 2×10^{-8}. The acid HF, option (B), will have a pH = 1.73 from $6.8 \times 10^{-4} = [H^+]^2/0.50$ and $[H^+] = 0.018$. The $[H^+]$ of a 0.50 M solution of C_6H_5OH, selection (D), $= 2.2 \times 10^{-5}$ from which the pH is 4.65.

The correct answer is (C).

[LO 6.16 SP 2.2]

20. For AgBr, $K_{sp} = [Ag^+][Br^-]$. If the solubility of AgBr is s, the one to one AgBr to Ag^+/Br^- mole ratio means that $K_{sp} = s_2$. Therefore, $s = 7.3 \times 10^{-7}$. Similarly, for AgCl, $K_{sp} = s^2$. $1.8 \times 10^{-10} = s^2, s = 1.3 \times 10^{-5}$. For a solubility of s for Ag_2CO_3 the $[Ag^+] = 2s$ and the $[CO_3^{2-}] = s$. Because $K_{sp} = [Ag^+]^2[CO_3^{2-}]$ $K_{sp} = 4s^3$ from which $s = 1.3 \times 10^{-4}$. The solubilities are 7.3×10^{-7} (AgBr), 1.3×10^{-5} (AgCl) and 1.3×10^{-4} (Ag_2CO_3). When these three compounds are arranged in order of increasing solubility, the order would be AgBr < AgCl < Ag_2CO_3.

The correct answer is (B).

[LO 6.21 SP 2.3]

21. All three compounds have 1:1 formulas so the K_{sp} for each is s^2 and the solubility given for each compound equals s. The K_{sp} for AgBr = $(7.3 \times 10^{-7})^2$ or 5.3×10^{-13}. For AgCN, the $K_{sp} = (7.7 \times 10^{-9})^2 = 5.9 \times 10^{-17}$. For AgSCN, $K_{sp} = (1.0 \times 10^{-6})^2$ or 1.0×10^{-12}. The most soluble (largest K_{sp}) is AgSCN with a $K_{sp} = 1.0 \times 10^{-12}$. The next most soluble with a K_{sp} of 5.3×10^{-13} is AgBr. The least soluble, with a K_{sp} of 5.9×10^{-17}, is AgCN When these values are arranged from most soluble to least soluble (i.e. largest K_{sp} to smallest K_{sp}) the order is AgSCN > AgBr > AgCN.

The correct answer is (D).

[LO 6.22 SP 2.3]

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22. With a $K_{sp} = 6.3 \times 10^{-10}$, $Mg(OH)_2$ is a slightly soluble compound with a $K_{sp} = [Mg^{2+}][OH^-]^2$. If the solubility of $Mg(OH)_2$ is s, $K_{sp} = 4s^3$ and $s = 5.4 \times 10^{-4}$. In comparison with this value for pure water, 0.10 *M* HCl will increase the solubility of $Mg(OH)_2$ because the H^+ ions will react with the OH^- ions in solution from the dissociation of $Mg(OH)_2$. This will cause the $Mg(OH)_2 \rightleftharpoons Mg^{2+} + 2\,OH^-$ equilibrium to shift toward the products, increasing the solubility of $Mg(OH)_2$. As common ions in the solubility equilibrium, the addition of OH ions (from NaOH) and Mg^{2+} ions (from $MgCl_2$) will both decrease the solubility of $Mg(OH)_2$. For 0.10 *M* NaOH, selection (B), the solubility of $Mg(OH)_2$ is $6.3 \times 10^{-10}/(0.10)^2$, or 6.3×10^{-8}. The 0.10 *M* $MgCl_2$, option (C), will yield 0.10 *M* Mg^{2+} ions, so the $[OH^-]$ will equal $(6.3 \times 10^{-10}/0.10)^{1/2}$ or 7.9×10^{-5}. From the relationship that the $[OH^-] = 2s$, the solubility of $Mg(OH)_2$ is 4.0×10^{-5} *M*. To summarize, the solubility of $Mg(OH)_2$ for these various conditions is given in the table below.

0.10 *M* HCl	0.10 *M* NaOH	0.10 *M* $MgCl_2$	H_2O
$> 5.4 \times 10^{-4}$	6.3×10^{-8}	4.0×10^{-5}	5.4×10^{-4}

Thus, the solubility of $Mg(OH)_2$ will increase in 0.10 *M* HCl, while 0.10 *M* $MgCl_2$ and NaOH will decrease its solubility, with NaOH having the greater effect because the $[OH^-]$ is squared.

The correct answer is (B).

[LO 6.23 SP 5.1]

23. Of the four compounds listed, three have anions of strong acids. These are AgBr, choice (A), $AgNO_3$, option (C),and AgI, selection (D). Adding a strong acid will not affect the solubility of a compound containing the anion of a strong acid, because there is little attraction between H^+ and these anions. In contrast, Ag_2CO_3, alternative (B), contains the anion of the weak acid (H_2CO_3). Such anions react with H^+ from the strong acid, causing the equilibrium between the insoluble Ag_2CO_3 and its ions (Ag^+ and CO_3^{2-}) to shift toward the ions, thereby increasing the solubility of the Ag_2CO_3.

The correct answer is (B).

[LO 6.23 SP 5.1]

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24. The equation shows that gaseous substances are reacting to form bonds between M^{3+} and H_2O. Bond formation releases energy, making the enthalpy change negative and $\Delta H < 0$. As the gaseous species enter the aqueous phase, they acquire greater order leading to a decrease in entropy, so $\Delta S < 0$. The entropy change will be even more negative as the H_2O molecules become bonded to the M^{3+} ion. Choice (A), $\Delta H < 0, \Delta S < 0$, shows the proper signs. Alternative (B), $\Delta H < 0, \Delta S > 0$, has the proper decrease in enthalpy but shows the entropy increasing. Option (C), $\Delta H > 0, \Delta S < 0$, corresponds to an endothermic reaction with a decrease in entropy. Selection (D), $\Delta H > 0, \Delta S > 0$, shows increases for both the enthalpy and entropy.

The correct answer is (A).

[LO 6.24 SP 1.4]

25. The relationship between K and ΔG° is $\Delta G^\circ = -RT\ln K$ from which $K = e^{-\Delta G^\circ/RT}$. Alternative (A), $K_p = \Delta G^\circ / RT$, omits both the exponential relationship and the negative sign. Choice (B), $K_p = -\Delta G^\circ / RT$, includes the negative sign but has omitted the exponential term. Option (C), $K_p = e^{\Delta G^\circ / RT}$, correctly indicates that K is related to ΔG° exponentially but has omitted the negative sign. Selection (D), $K_p = e^{-\Delta G^\circ/RT}$, gives the correct relationship.

The correct answer is (D).

[LO 6.25 SP 2.3]

26. The relationship between K and ΔG° is $\Delta G^\circ = -RT\ln K$. The negative sign indicates that ΔG° and K are inversely related while the ln K means that K will always be positive, unlike ΔG°, which can be either positive or negative. A large negative value of ΔG° corresponds to a highly spontaneous reaction in which the products are much more abundant than reactants. This corresponds to a large positive K value, choice (A). Option (B), a small positive value of K, corresponds to a small positive value for ΔG°. Selections (C) and (D), which refer to negative K values are both impossible, because K can not be less than zero.

The correct answer is (A).

[LO 6.25 SP 2.3]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) i. The equilibrium expression is written by multiplying the concentrations of the products by one another. That product is divided by the concentrations of the reactants, omitting the concentrations of any substances that do not change, such as solids or pure liquids. For the Water Gas Reaction, the C(*s*) is omitted because it is a solid. Thus, the *K* expression is $K = [CO][H_2]/[H_2O]$.

ii. For the Water Gas Shift Reaction, all substances in the balanced equation are gases, so all will be included in the equilibrium expression and that expression, is $K = [CO_2][H_2]/[CO][H_2O]$.

iii. The overall equation for the reaction between C(s) and H_2O can be obtained by adding the equations for the Water Gas Reaction and the Water Gas Shift Reaction to give $C(s) + 2\,H_2O(g) \rightleftharpoons CO_2(g) + 2\,H_2(g)$. The CO(g), a product in the WGR equilibrium expression and a reactant in the Water Gas Shift Reaction, cancel out. The equilibrium expression for this reaction will be: $K = [CO_2][H_2]^2/[H_2O]^2$. In this expression, the C(s) has been omitted, and the $[H_2]$ and $[H_2O]$ are both squared due to their coefficients of 2 in the balanced equation. This expression can also be obtained by multiplying the *K* expressions for the individual reactions.

(b) i. The Water Gas Reaction is endothermic ($\Delta H = 131$ kJ/mol) so an increase in T will increase the quantity of H_2.

ii. An increase in pressure will decrease the quantity of H_2 at equilibrium because there are more moles of gas in the products. An increase in pressure will cause the equilibrium to shift toward the reactants which occupy a smaller volume.

(c) i. The Water Gas Shift Reaction is exothermic with $\Delta H = -41$ kJ/mol. An increase in temperature will produce a decrease in the quantity of H_2 because the equilibrium will shift to remove the stress introduced by the temperature increase. The extra heat introduced by an increase in temperature can be dissipated (partially, at least) with a shift toward the reactants, decreasing the quantity of H_2.

ii. An increase in pressure will have no effect on the Water Gas Shift Reaction, because the reactants and products contain equal moles of gas. An increase (or decrease) in pressure will not favor either side of the equilibrium.

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(d) i. For the overall reaction (or any reaction), adding C(s) will have no effect, because C is a solid and does not appear in the equilibrium expression.

ii. The quantity of $H_2(g)$ will be decreased with an increase in pressure, because there are more moles of gas in the products and the equilibrium will shift toward the reactants to offset the increased pressure.

iii. The quantity of $H_2(g)$ will increase with an increase in temperature, because the overall reaction is endothermic (131 kJ/mol − 41 kJ/mol = 90 kJ/mol). Thus, added heat will promote the forward reaction.

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2. (a) The pressure of HI before any reaction occurs can be found from the Ideal Gas Equation, $P = nRT/V$. $P = 0.010(0.0821)(800/1.0)$. $P = 0.657$ atm = 0.66 atm.

(b) The pressures for the various species at equilibrium can be found by setting up an ICE table

$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$ $\qquad K = [HI]/[H_2][I_2]$

	HI P, atm	H_2 P, atm	I_2 P, atm
Initial	0.657	0	0
Change	–2x	+x	+x
Equilibrium	0.657 – 2x	x	x

$K = P_{HI}^2/P_{H_2} \times P_{I_2}$

$62.5 = (0.657 - 2x)^2/x^2$

While this equation can be solved in the full quadratic form, it can be simplified substantially by taking the square root of both sides to give $7.91 = (0.657 - 2x)/x$

From this, $7.91\,x = 0.657 - 2x$

$9.91\,x = 0.657$

$x = 0.0663$

$P_{H_2} = P_{I_2} = 0.0663$ atm $\qquad P_{HI} = 0.524$ atm

(c) $Q = P_{HI}^2/P_{H_2} \times P_{I_2}$

$Q = 0.10/(0.10)(0.020)$

$Q = 50$

Because Q (50) is less than K (62.5), the equilibrium will shift to form HI.

(d) K_c will equal K_p. Although $K_p = K_c\,(RT)^{\Delta n}$. Because the moles of gas are equal for the reactants and products, $\Delta n = 0$ and $(RT)^{\Delta n} = 1$.

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3. (a) $CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$ $K_a = [H^+][CH_3COO^-]/[CH_3COOH]$

(b) For a 0.10 *M* solution of CH_3COOH

	$[CH_3COOH]$	$[H^+]$	$[CH_3COO^-]$
Initial	0.10	0	0
Change	−x	+x	+x
Equilibrium	0.10 − x	x	x

$K = [H^+][CH_3COO^-]/[CH_3COOH]$

$1.8 \times 10^{-5} = x^2/(0.10 - x)$

Making the assumption that $x \ll 0.10$

$1.8 \times 10^{-5}\,(0.10) = x^2$

$x = [H^+] = [CH_3COO^-] = 1.34 \times 10^{-3}$ *M*. The $[CH_3COOH] = 0.10$ *M*.

(c) If 0.0050 mol of CH_3COONa is added to 100 mL of 0.10 *M* CH_3COOH the CH_3COO^- concentration is 0.0050/0.10 or 0.05 M. The concentrations are $[CH_3COOH] = 0.10$ and $[CH_3COO^-] = 0.050$

$1.8 \times 10^{-5} = [H^+][CH_3COO^-]/[CH_3COOH]$

$1.8 \times 10^{-5} = [H^+][0.050]/[0.10]$

$1.8 \times 10^{-5}\,(0.10)/(0.050) = [H^+]$. The $[H^+] = 3.6 \times 10^{-5}$ *M*.

(d) K_a decreases as the temperature increases, so $\Delta H°$ is negative.

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CHAPTER 9

THERMODYNAMICS

1. A reaction is spontaneous at all temperatures when ΔH is negative and ΔS is positive. It is always non-spontaneous when ΔH is positive and ΔS is negative.

   The correct answer is (B).

   [LO 5.13 SP 2.2, 2.3, 6.4]

2. A reaction with positive values for both ΔH and ΔS is non-spontaneous at low temperatures but spontaneous as temperature is increased.

   The correct answer is (B).

   [LO 5.13 SP 2.2, 2.3, 6.4]

3. To change liquid water to gaseous water requires input of energy ($\Delta H +$) and disorder increases ($\Delta S +$).

   The correct answer is (A).

   [LO 5.13 SP 2.2, 2.3, 6.4]

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4. The amount of heat energy lost by the hot water must equal the heat gained by the cold water. Since $q = m\,c\,\Delta T$, it follows that ΔT is about 20°C.

   The correct answer is (C).

   [LO 5.5 SP 2.2]

5. $q = m\,c\,\Delta T$ so 50. J = (10.0 g)(c)(10°C).

   The correct answer is (B).

   [LO 5.5 SP2.2]

6. $q = m\,c\,\Delta T$ so 7500 J = (25 g)(4.184 J/g°C) (a bit less than 75°C) by estimation. This means a final temperature just less than boiling.

   The correct answer is (C).

   [LO 5.5 SP 2.2]

7. Natural gas is 80-90% methane with much smaller amounts of ethane, propane, and butane included in the mixture.

   The correct answer is (B).

   [LO 5.8 SP 4.2, 5.1]

8. Energy is required to melt any substance, an endothermic process. The other processes all give off energy (exothermic).

   The correct answer is (D).

   [LO 5.6 SP 2.2, 2.3]

9. The cold pack's endothermic reaction draws heat energy away from the injured body part and is perceived as being cold. In order for an endothermic reaction to be spontaneous, disorder must increase.

   The correct answer is (A).

   [LO 5.12 SP 1.2]

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10. Situation (A) increases order (decreases disorder) and situation (C) has little change in entropy (two moles of gases, each one molecule with one bond, change to two moles of gases, each with one bond). Both situation (B) and (D) change from a more ordered phase to a more disordered one but (B) changes all the way from a solid to a gas (sublimation).

    The correct answer is (B).

    [LO 5.12 SP 1.4]

11. A reaction with positive values for both ΔH and ΔS is non-spontaneous at low temperatures but spontaneous as temperature is increased. Remember to make the units agree between ΔH (by convention in kJ mol^{-1}) and ΔS (usually in J mol^{-1} K^{-1}). One would arrive at answers (A) and (B) by mis-remembering the sign conventions for Gibb's equation. Answer (D) would give a temperature where the reaction had not yet attained spontaneity because the temperature would be too low.

    The correct answer is (C).

    [LO 5.12 SP 1.4]

12. Answer (A) is a mis-statement of the First Law. Answer (B) is a partial statement of the Second Law. Answer (C) implies incorrectly that the entropy of the universe is constant. Answer (D) gives a baseline value for entropy and it is one way to correctly state the Third Law.

    The correct answer is (D).

    [LO 5.12 SP 1.4]

13. Answer (A) is a correct definition of "work" but it does not answer the question. Answer (B) is one way of stating the First Law. Answer (C) is one way of stating the Second Law. Answer (D) is a correct statement but it does not answer the question.

    The correct answer is (B).

    [LO 5.4 SP 1.4, 2.2]

14. Entropy increases in any spontaneous process, leading to an increase of entropy in the universe.

    The correct answer is (C).

    [LO 5.12 SP 1.2]

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15. The liquid form of a substance is more ordered by far than the chaotic gaseous state. Answers (B), (C), and (D) all show an increase in entropy. Only answer (A) shows a more ordered product.

    The correct answer is (A).

    [LO 5.12 SP 1.4]

16. Answer (A) is a theoretical definition of the link between ΔG and work, although it is unlikely that this could occur completely. ΔH is just one component of ΔE so (B) is incorrect. Answers (C) and (D) seem to be partial applications of the Gibbs equation.

    The correct answer is (A).

    [LO 5.4 SP 1.4, 2.2]

17. A negative value of ΔG indicates spontaneity, a reaction that will progress to the product side. An equilibrium constant K greater than 1 indicates a ratio of more products to fewer reactants. Answer (A) is impossible, answer (B) indicates a non-spontaneous reaction, and answer (C) would be unlikely but possible.

    The correct answer is (D).

    [LO 5.17 SP 6.4]

18. Anyone who has used a butane lighter knows that this reaction is spontaneous so ΔG must be negative. The reaction is clearly exothermic so ΔH must be negative. The balanced reaction shows fifteen moles of gaseous reactants but eighteen moles of gaseous products so ΔS must be positive.

    Thus the correct answer is (C).

    [LO 5.13 SP 2.2, 2.3, 6.4]

19. ΔH_f values are zero by definition for elemental forms under standard conditions. Thus the values for answers (A), (B), and (C) are each zero. Oxidation of carbon is an exothermic process and ΔH_f must have a negative value.

    The correct answer is (D).

    [LO 5.8 SP 2.3, 7.1, 7.2]

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20. Answers (A), (B), and (D) are all ways of stating portions of Hess' Law or important underlying facts. Answer (C) is an incorrect statement since the heats of formation are additive as are the supporting reactions. While some of the chemical species in the reactions and their heats of formation may be cancelled, some must remain to be added.

    The correct answer is (C).

    [LO 5.8 SP 2.3, 7.1, 7.2]

21. A spontaneous chemical reaction must have a negative ΔG but the value of ΔS could have any sign, depending on context (the value of ΔH is key). While answers (A), (B), and (C) could be true in some context, answer (D) will always be true. Be sure to select the best answer!

    The correct answer is (D).

    [LO 5.13 SP 2.2, 2.3, 6.4]

22. H_2O is a more complicated molecule than H_2 is, so answers (A) and (B) are not suitable. A substance in the gaseous state has greater entropy than that of the liquid state so answer (C) is a better choice than answer (D).

    The correct answer is (C).

    [LO 5.12 SP 1.4]

23. A negative value for ΔS indicates that the situation is becoming more ordered. Answer (A) shows a solid becoming ions in solution, a more disordered situation. Answer (C) shows a gas escaping from an aqueous solution, a more disordered situation. Answer (D) shows a reaction wherein eight moles of gaseous reactants become eleven moles of gaseous products, a more disordered situation. In answer (B), two moles of reactants, one a gas, become one mole of solid product. This is a more ordered situation and the sign of ΔS must be negative.

    The correct answer is (B).

    [LO 5.12 SP 1.4]

24. The salt with the fewest number of ions will have the smallest value for entropy. NaCl has two ions while the other salts have three, four, or five ions per salt.

    The correct answer is (C).

    [LO 5.12 SP 1.4]

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25. As a car battery discharges, the voltage drops until it becomes zero, an equilibrium situation. So ΔG increases as the reaction becomes less spontaneous, eventually reaching a value of zero as the battery discharges.

The correct answer is (D).

[LO 5.14 SP 2.2]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) Use Hess' Law:

$$\Delta H^\circ = [2\Delta H_f\,(HI)] - [\Delta H_f\,(H_2) + (\Delta H_f\,(I_2)]$$
$$= [2 \times 26.0] - [0.0 + 0.0]$$
$$= (+52.0\ \text{kJ})$$

[LO 5.6 SP 2.2, 2.3]

(b) Use a pattern similar to Hess' Law but use entropy values:

$$\Delta S^\circ = [2 \times 206.0] - [130.6 + 116.1]$$
$$= (+165.3\ \text{J})$$

[LO 5.12 SP 1.4]

(c) A Hess' Law-like procedure cannot be used in this case because ΔG_f values are not provided. Instead use the Gibbs equation and be sure to make all units agree:

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= (+52.0\ \text{kJ mol}^{-1}) - [298\ \text{K}\,(0.1653\ \text{kJ mol}^{-1}\ \text{K}^{-1})]$$
$$= (2.7\ \text{kJ})$$

[LO 5.13 SP 2.2, 2.3, 6.4]

(d)
$$\Delta G^\circ = -RT \ln K$$
$$(+2.7\ \text{kJ}) = -(0.0083145\ \text{kJ mol}^{-1}\text{K}^{-1})(298\ \text{K}) \ln K$$
$$K_{eq} = (3.36 \times 10^{-1})$$

[LO 5.17 SP 6.4]

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2. (a) $J = (1\,g\,H_2O)(1\,mol\,H_2O/18.02g\,H_2O)(6.01\,kJ/1\,mol\,H_2O)(1000\,J/1kJ)$
$= 333.5\,J$

[LO 5.6 SP 2.2, 2.3]

(b) ΔG = zero by definition since the phase change represents an equilibrium.

[LO 5.14 SP 2.2]

(c) $\Delta G = \Delta H - T\Delta S$
$0 = (333.5\,J) - 273\,K\,(\Delta S)$
$\Delta S = 1.22\,J\,g^{-1}\,K^{-1}$ or $22\,J\,mol^{-1}\,K^{-1}$

[LO 5.13 SP 2.2, 2.3, 6.4]

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3. (a) $5\,B(s) + 4.5\,H_2(g) \rightarrow B_5H_9(g)$

[LO 3.2 SP 1.5, 7.1]

(b) i. $2\,B_5H_9(g) + 12\,O_2(g) \rightarrow 5\,B_2O_3(g) + 9\,H_2O(g)$

[LO 3.2 SP 1.5, 7.1]

ii. $\Delta H = [5\,\Delta H_f\,(B_2O_3) + 9\Delta H_f\,(H_2O)] - [2\Delta H_f\,(B_5H_9) + 12\Delta H_f\,(O_2)]$

$= [5(-1264) + 9(-285.8)] - [2(62.8) + 12(0)]$

$= [-8892.2] - [125.6]$

$= -9017.8\ kJ/2mol\ B_5H_9$

$= -4509\ kJ/mol B_5H_9$

[LO 5.8 SP 2.3, 7.1, 7.2]

(c) i. $2B(s) + 3\,H_2(g) \rightarrow B_2H_6(g)$

[LO 3.2 SP 1.5, 7.1]

ii. Use Hess' Law to manipulate these equations so that their sum is the same as the formation equation in (C) i. To do this, reverse the first equation (and change the sign of ΔH to +2035). Multiply the third equation by three and the fourth equation by three (and be sure to multiply the heat values as well). Then the sum will be $(+2035) + (-1273) + 3(-286) + 3(+44) = +36$ kJ.

$2B(s) + 3\,H_2(g) \rightarrow B_2H_6(g) \qquad \Delta H = +36$ kJ

[LO 5.8 SP 2.3, 7.1, 7.2]

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4. i. $2\,C_4H_{10}(g) + 13\,O_2(g) \rightarrow 8\,CO_2O(g) + 10\,H_2O(g)$

[LO 5.8 SP 2.3, 7.1, 7.2]

ii. An alternative way to calculate ΔH is to total the energies of bonds broken, then to subtract the total energies of bonds formed. It may be helpful to sketch the molecules so that you do not miss any of the bonds in question.

$\Delta H = [6(348) + 20(413) + 13(485)] - [16(728) + 20(463)]$

$= -4255\ \text{kJ}/2\ \text{mol}\ C_4H_{10}$

$= -2128\ \text{kJ/mol}\ C_4H_{10}$

[LO 5.8; SP 2.3, 7.1, 7.2]

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CHAPTER 10

ACIDS AND BASES

1. The pH of a solution is defined as the –log of the $[H^+]$. For a 0.0001 *M* HNO_3 solution, a strong acid, the $[H^+]$ is 0.0001 *M*, and the pH is $-\log(0.0001) = 4$, because the –log of 1×10^{-4} is 4.

   The correct answer is (A).

   [LO 6.15 SP 2.2,2.3,6.4] [LO 6.19 SP 2.3, 4.2, 6.4]

2. Referring to the summary chart of physical and chemical properties at the beginning of Chapter 10, we see that bases do indeed typically feel slippery to the touch (soap and shampoo). Because the $[OH^-]$ is greater than the $[H^+]$, the pH's of basic solutions are above 7.0. According to the Bronsted and Lowry model, bases are proton acceptors. CO_3^{2-} ions can accept H^+ ions and produce H_2O and CO_2 (from H_2CO_3). Answers (A), (B) and (D) are all properties of bases. However, it is the acids that are capable of reacting with numerous metals. For example, a common high school experiment involves reacting HCl with zinc or magnesium to produce H_2 gas.

   The correct answer is (B).

   [LO 6.11 SP 1.1, 1.4, 2.3]

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3. A conjugate acid is the product-side acid which forms when the original base accepts a proton. Answers (A), the $Br^-(aq)$, and (B), the $S^{2-}(aq)$, do not include an acid; and answer (D) , HI, is a strong acid, and does not exist in molecular form in aqueous solution. Then NH_4^+ is the conjugate acid of a weak base, NH_3.

   The correct answer is (C).

   [LO 6.19 SP 2.3, 5.1, 6.4]

4. A conjugate base is the product-side base that forms when a strong acid donates its proton. Answer (C), as explained in question 3 is the conjugate acid of a weak base. If the strong acid, HBr, donates its proton, the Br^- ion remaining becomes the conjugate base.

   The correct answer is (A).

   [LO 6.19 SP 2.3, 5.1, 6.4]

5. HI is one of the strongest inorganic acids, along with HBr, HCl, HNO_3, $HClO_4$ and H_2SO_4. The NH_4^+ ion is a weak acid, with a p*K*a of 9.25, formed when NH_3 captures a proton.

   The correct answer is (C).

   [LO 6.11 SP 1.1, 1.4, 2.3]

6. The solution is a buffer solution containing equal amounts of NH_4^+ and NH_3. The K_b expression would be $\frac{[NH_4^+][OH^-]}{[NH_3]}$. If water is added, with equal moles of of NH_4^+ and NH_3, the concentrations will drop to the same value and continue to cancel out of the expression. Therefore, the $[OH^-]$ and pOH, and consequently, the pH will not change.

   The correct answer is (C).

   [LO 6.2 SP 6.4]

7. Strong acids are those which effectively ionize or dissociate 100% in aqueous solutions. Weak acids are only partially ionized. Therefore, the correct answer is (C), the extent of the dissociation of the electrolytes.

   The correct answer is (C).

   [LO 6.17 SP 6.4]

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8. Concentrated solutions are ones with large amounts of reactant dissolved per liter, and dilute solutions are those with low numbers of moles of reactants dissolved. Therefore, the correct answer is (A), the number of moles present per liter.

   The correct answer is (A).

   [LO 6.1 SP 6.2]

9. In a 0.01 *M* HCl solution, a strong acid, the $[H^+]$ will also be 0.01 *M*. The –log of 0.01 is 2, so the pH of the solution is 2. In a 0.0001 *M* HCl, solution which will also be 100% dissociated, the $[H^+]$ will also be 0.0001 *M*. The –log of 0.0001 is 4. It is because both of the solutions do ionize to 100%, the $[H^+]$ from which the pH is calculated, is the same as the molarity of the original solution.

   The correct answer is (C).

   [LO 6.16 SP 2.2, 6.4] [LO 6.7 SP 2.2, 2.3]

10. The moles of HNO_3 will be the same before and after the solution is diluted. Moles in a solution are calculated by Liters × molarity. The 0.0030 *M* solution will be diluted to 300 ml once the 200 mL of water is added to the container. The 0.0030 *M* will be reduced by a factor of $\frac{100\text{ mL}}{300\text{ mL}}$ or 1/3. One third of 0.003 *M* is 0.001 *M*, or 1.0×10^{-3} *M*. The –log of 10^{-3} is 3.0.

    The correct answer is (A).

    [LO 6.16 SP 2.2, 6.4] [LO 6.7 SP 2.2, 2.3]

11. A Bronsted-Lowry acid is a proton donor. C_2H_5OH is a non-electrolyte, molecular compound in which the atoms are covalently bonded. The compound KOH is an ionic compound which will ionize in aqueous solution to produce K^+ ions and OH^- ions, thus forming a basic solution. The $NaHSO_4$ is also an ionic compound containing the Na^+ ion and the HSO_4^-. In aqueous solution the HSO_4^- ion is a Bronsted-Lowry acid; it reacts with water according to the equation, $HSO_4^- + H_2O \rightarrow H_3O^+$ and SO_4^{2-}.

    The correct answer is (B).

    [LO 6.16 SP 2.2, 6.4] [LO 6.7 SP 2.2, 2.3]

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12. The compound NH_3 will react with water according to the equation: $NH_3 + H_2O$ to $\rightarrow NH_4^+$ and OH^-, forming a basic solution. The $HSO_4^- + H_2O \rightarrow H_3O^+$ and SO_4^{2-}, forming an acidic solution. The compound KOH is an ionic compound which will ionize in aqueous solution to produce K^+ ions and OH^- ions, thus forming a basic solution. The C_2H_5OH is a non-electrolyte, molecular compound in which the atoms are covalently bonded. In water, the compound remains in its molecular form: no ions are formed; no protons are either accepted nor donated.

The correct answer is (C).

[LO 6.11 SP 1.1, 1.4, 2.3]

13. The only basic solutions will be the answers (D) and (A), as shown in the equations discussed in answers to question 12. The KOH will dissolve to produce OH^- ions. Basic solutions contain more OH^- ions than H^+. NH_3 will do the same thing, but because it is classified as a weak base, there will be typically less than 5% ionization. A higher concentration of OH^- ions will be present in the KOH solution. The pOH of 0.1 *M* KOH = 1. The pH = 14 – pOH = 13.

The correct answer is (A).

[LO 6.11 SP 1.1, 1.4, 2.3]

14. The second, third and fourth volumes (33.50, 33.49. and 33.51 respectively,) are all within 0.01 mL of one another, very precise, but the first volume, 32.25 mL, is appreciably lower. The number of drops of phenolphthalein or a few more mL of water would not change the moles of acid present, and therefore would not change the volume of base needed for neutralization. If the buret were not rinsed with base, it would be diluted, and the titration would require a larger volume. If the pipet were not rinsed with acid, the acid would be slightly diluted and fewer moles of acid would enter the flask. This would necessitate a lower volume of base in the titration.

The correct answer is (D).

[LO 6.13 SP 5.1]

15. The lowest pH is associated with the most acidic solution. Answer (B), NaCl will be a neutral solution. Answer (A), the NaOH will produce OH^- ions, forming a basic solution. The acetate ions in $NaC_2H_3O_2$ will react according to the reaction $C_2H_3O_2^-(aq) + H_2O \rightarrow HC_2H_3O_2 + OH^-$. This will be a basic solution. The aluminum will undergo hydrolysis: $Al(H_2O)_6^{3+} + H_2O \rightarrow Al(H_2O)_5OH^{2+}$ and H_3O^+ (Please see the discussion in the hydrolysis section of the text in Chapter 10.) With a +3 oxidation number on aluminum, a large number of H_3O^+ ions will result and a very acidic solution with a low pH is produced.

The correct answer is (D).

[LO 6.15 SP 2.2, 2.3, 6.4]

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16. With a solution pH of 8.2, the solution is weakly basic. The acetate ions in $NaC_2H_3O_2$ will react according to the reaction $C_2H_3O_2^-$ (aq) + $H_2O \rightarrow HC_2H_3O_2 + OH^-$. This will be a basic solution. but, because the reaction occurs to less than 5% , it will not be strongly basic. The pH of a 0.1 *M* NaOH will be = 13, because it ionizes 100%.

The correct answer is (C).

[LO 6.12 SP 1.4]

17. For the pH to remain the same when more water is added, the solution will contain neither OH^- ions nor H_3O^+ ions. A neutral compound which does not undergo hydrolysis is NaCl.

The correct answer is (B).

[LO 6.15 SP 2.2, 2.3, 6.4]

18. The outer limits on the pH scale are not necessarily 0 to 14. A 10 *M* HCl will produce roughly 10 *M* hydrogen ion concentration. The pH is $-\log[H^+]$, and the –log of 10 is –1. This means the pH will be = to –1. The pH and pOH will merely add up to 14 as long as the solution exists at room temperature. (A) is not true. The ionization of water is endothermic and produces 10^{-7} *M* H^+ ions and 10^{-7} *M* OH^- ions. This is a neutral solution, but at 95°C., the dissociation occurs to a greater extent and produces 10^{-6} *M* H^+ ions and 10^{-6} *M* OH^- ions. The pH of this solution is 6.0, but the pOH is also 6.0 (and the *K*w = 1×10^{-12}). Because there are equal amounts of each, the solution will still be neutral, so answer (C) is false. If HNO_3 were sufficiently diluted, the H^+ ions may be barely detectable, but the pH would not rise above 7, that of a neutral water solution, making answer (D) a false statement. The weaker the acid, the stronger the attraction between the H^+ and the anion portion. Consequently, when the anion is added to water, the more it will react (undergo hydrolysis) to capture and retain the H^+.

The correct answer is (B).

[LO 6.14 SP 2.2, 6.2]

19. With the endothermic dissociation of water, $H_2O \rightleftharpoons H^+ + OH^-$, at room temperature, the ionization of water produces 10^{-7} *M* H^+ ions and 10^{-7} *M* OH ions. This is a neutral solution, but at 95°C, the dissociation occurs to a greater extent and 10^{-6} *M* H^+ ions and produces 10^{-6} *M* OH^- ions. The pH of this solution is 6.0, but the pOH is also 6.0 (and the *K*w will be = to 1×10^{-12}). Because there are equal amounts of each, the solution will still be neutral, when some room temperature water is heated to boiling.

The correct answer is (C).

[LO 6.14 SP 2.2, 6.2]

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20. The method which would most likely be used to determine the molar mass of an unknown solid acid would be that of titrating a known mass of the solid unknown with base of known concentration. From the volume and concentration of base, the moles of base could be calculated. Then the moles of acid could be determined, based upon the stoichiometry of the neutralization reaction. With its mass already known, its molar mass could be determined.

The correct answer is (D).

[LO 1.15 SP 6.4] [LO 1.16 SP 4.2, 5.1] [LO 6.13 SP 5.1]

21. Mass spectroscopy would be used to determine the number of and relative abundance of isotopes of an element, so answer (B) is incorrect. Answer (C), PES, would be used to determine the energy required to remove either outer or core electrons. Titrations would be used as explained in the answer to question 20, so answer (D) is also inappropriate for this analysis. To determine the wavelength of maximum absorbance for an aqueous $CuSO_4$ solution, a turquoise blue solution, the solution would be placed in a spectrophotometer and its absorbance monitored at different wavelengths to detect the wavelength where the solution absorbed the greatest amount of light.

The correct answer is (A).

[LO 1.15 SP 6.4] [LO 1.16 SP 4.2, 5.1] [LO 6.13 SP 5.1]

22. The HX will ionize to produce a *K*a expression: $Ka = \frac{[H^+][X^-]}{[HX]}$. If the entire titration requires 50.0 ml of KOH, after the addition of 30 mL, (when the pH is 5.0) one is 30/50 or 3/5 through the titration, so 3/5 of the original acid is now in the X^- form and 2/5 remains in the acid HX form. The *K*a expression can now be written as $Ka = \frac{[10^{-5}][3/5]}{[2/5]}$. This simplifies to 1.5×10^{-5} for the value of *K*a.

The correct answer is (A).

[LO 6.19 SP 5.1, 6.4] [LO 6.20 SP 6.4]

23. The pH is calculated as the –log of $[H^+]$. The –log of 1.0 is zero. Therefore the pH of the 1.0 *M* HI solution will be 0.0.

The correct answer is (A).

[LO 6.15 SP 2.2, 2.3, 6.4] [LO 6.19 SP 5.1, 6.4]

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24. The pOH of the KOH must be calculated before the pH can be known. The pOH is $= -\log[OH^-]$. Here, the $-\log(0.01)$ or $-\log(10^{-2})$ is equal to 2.0. Because the pH + pOH = 14 at room temperature, if the pOH is 2.0, $14 - 2.0 =$ pH $= 12$.

    The correct answer is (D).

    [LO 6.15 SP 2.2, 2.3, 6.4]

25. Amphoteric refers to a hydroxide-containing compound capable of neutralizing either acids or bases. This term is often confused with amphiprotic- capable of donating or accepting a proton. Answer (A) with tthe Al^{3+} and answer (B), the $Al(H_2O)_6^{3+}(aq)$ do not contain OH^- ions. Answer (C) showsAl$(OH)_3(s) \rightarrow Al^{3+}(aq) + 3OH^-(aq)$, which is merely the dissolving and ionizing of the compound into its constituent ions. Answer (D) shows the $Al(OH)_3$ neutralizing a base. $(Al(OH)_3 + OH^-(aq) \rightarrow Al(OH)_4^-(aq)$.

    The correct answer is (D).

    [LO 6.11 SP 1.1, 1.4, 2.3]

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) $HY + H_2O \Leftrightarrow H_3O^+ (aq) + Y^- (aq)$
$Ka = [H_3O^+][Y^-]/[HY]$

[LO 6.11 SP 1.1, 1.4, 2.3]

(b) $HY + OH^- \rightarrow H_2O + Y^-$

[LO 6.11 SP 1.1, 1.4, 2.3]

(c) The units on molar mass are g/mole. The moles of the monoprotic acid will be the same as the moles of base added. The moles of base added = $0.030\ L \times 0.10\ mol/L = 0.00300$ moles .The molar mass = $0.426g/0.0030$ moles = **142 g/mole = 140 g/mole**, with 2 significant digits.

(d) A short cut is possible here because the addition of the first 6.0 mL of base is 1/5 through the titration to the equivalence point of 30.00 mL Therefore 4/5 of the original moles of acid remain and 1/5 of the original moles is now in the Y^- form. The pH = 5.00, indicating the $[H_3O^+] = 1 \times 10^{-5}$M. Using the *K*a expression from part (a), $Ka = \frac{[H_3O^+][Y^-]}{[HY]}$ and substituting in what we know, the $Ka = \frac{[1 \times 10^{-5}][1/5\ vol]}{[4/5\ vol]}$. (Note: Because the volume term cancels out, it is not necessary to insert the actual volume of 0.056L). This leaves $Ka = 1/4 \times 10^{-5} \rightarrow 2.50 \times 10^{-6}$.

(e) In aqueous solution at room temperature, $K_a \times K_b = 1 \times 10^{-14}$, for an acid and its conjugate base. In step D, we determined the *K*a to be = 2.50×10^{-6}. Therefore, $1 \times 10^{-14} = (2.5 \times 10^{-6})(K_b)$, so $K_b = 4.00 \times 10^{-9}$.

(f) As the Y^- ion is produced, (Part B), Y^- is a weak base as indicated by its Kb value, and it will react with water molecules (hydrolyze) as illustrated in the equation: $Y^- + HOH \rightarrow HY + OH^-$. Therefore one can accurately predict that the solution will be BASIC at the equivalence point and not neutral. All the original HY acid has reacted, so the solution will no longer be acidic.

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(g) The equilibrium expression for the reaction: $Y^- + HOH \rightarrow HY + OH^-$ is $K_b = \dfrac{[HY][OH^-]}{[Y^-]}$

and we know the K_b value from part E above. The stoichiometry is 1:1 for the products, so if we let x = $[OH^-]$, [HY] is also = to x. The solid is first dissoved in the 50.0 mL H_2O. The $[Y^-]$ is 0.003 moles/total volume of 80 mL = 0.003 moles / .080L = 3.75×10^{-2} *M*

. $K_b = 4.00 \times 10^{-9} = \dfrac{[HY][OH^-]}{[Y^-]}$ which becomes $4.00 \times 10^{-9} = \dfrac{x^2}{3.75 \times 10^{-2}\ M}$

, x = 1.23×10^{-5} *M* = $[OH^-]$. ThepOH = $-\log[OH^-] = -\log 1.23 \times 10^{-5}\ M = 4.91$. The pH = 14 – pOH = 14 – 4.91, which leads to the **pH = 9.09** (reaffirming the basic nature of the solution at the equivalence point).

[LO 6.11 SP 1.1, 1.4, 2.3] [LO 6.12 SP 1.4] [LO 6.16 SP 2.2, 6.4] [LO 6.17 SP 6.4]

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2. $HMyst + H_2O \Leftrightarrow H_3O^+ + Myst^-$
   $Ka = 1 \times 10^{-5} = [H_3O^+][Myst]/[HMyst]$
   Let $x = [H_3O^+]$
   If $x = [H_3O^+]$, then x is also $= [Myst]$;
   $1 \times 10^{-5} = x^2/0.10$, so $x = 1.0 \times 10^{-3} M = [H_3O^+]$
   Percent dissociation $= ([H_3O^+]/[HMyst]) \times 100\% = (1 \times 10^{-3}\ M/0.10) \times 100 =$ **1%**

   [LO 6.12 SP 1.4]

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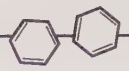

3. (1) Fill a buret (rinsed with distilled water then NaOH solution) with NaOH solution and record the initial volume reading.

   (2) Pipet 25.00 mL of the vinegar into a beaker and add 2-3 drops of phenolphthalein (visual cue) and 25 mL of water to the vinegar. Perform a "quick run" titrating by 3 mL increments to determine approximate equivalence pt. Color change of phenolphthalein can help determine the zone of pH change. Repeat the trial, using 2 mL increments , and decreasing the size of the increments until endpoint is achieved and pH = 9 – 10. Use 1-2 mL increments to a pH of 10. Record the volume and pH at each increment.

   (3) Graph the data to determine the exact equivalence point.

   (4) Calculation:
   - Vol (L) of NaOH at the equivalence pt $\times$ 0.20 moles/L = moles of NaOH = moles of $HC_2H_3O_2$.
   - Moles of $HC_2H_3O_2 \times 60.0$ g/moles = g $HC_2H_3O_2 \times$ (1 mL/1g$HC_2H_3O_2$ of vinegar) = (assuming the same density of water) mL of $HC_2H_3O_2$
   - mL of $HC_2H_3O_2$/25.00 mL $\times$ 100% = % $HC_2H_3O_2$ by volume

[LO 6.13 SP 5.1]

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4. Write the formula of the conjugate acid of each Bronsted-Lowry base. Bronsted-Lowry bases **accept protons** (H^+ ions) in neutralization reactions.

	Base	Conjugate Acid (after accepting a proton)
(a)	H_2O	H_3O^+
(b)	NH_2^-	NH_3
(c)	OH^-	H_2O (HOH)
(d)	HSO_3^-	H_2SO_3

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CHAPTER 11

ELECTROCHEMISTRY

1. The permanganate ion has a formula of MnO_4^-. The formula has four O atoms and one Mn atom. The only one of the four structures that has this ratio is choice (A). Option (B) has three atoms of one type and two atoms of another, which could correspond to the thiosulfate ion ($S_2O_3^{2-}$). Alternative (C) contains three atoms of the same type. Of the possible options it corresponds to the triiodide ion (I_3^-). Selection (D) contains two atoms of one type and seven of another. It represents the dichromate ion ($Cr_2O_7^{2-}$).

   The correct answer is (A).

   [LO 3.1 SP 1.5]

2. The dichromate ion has a formula of $Cr_2O_7^{2-}$, with two atoms of one type and seven of another. Alternative (A) shows one atom of one type and four of another as in the permanganate ion (MnO_4^-). Option (B), with two atoms of one type and three of another best represents the thiosulfate ion ($S_2O_3^{2-}$). Choice (C), with three atoms represents the triiodide (I_3^-) ion. Selection (D), with two atoms of one type and seven of another, provides a good representation of the dichromate ion with a formula of $Cr_2O_7^{2-}$.

   The correct answer is (D).

   [LO 3.1 SP 1.5]

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3. The oxidation number of a substance in a species can be found from the equation: Charge on species = [number of O atoms × (–2) + number of H atoms × (+1) + ox. no. of substance]. For the oxidation number of Cr in $Cr_2O_7^{2-}$, this becomes $-2 = [7(-2) + 2(Cr)]$ or $-2 + 14 = 2Cr$. $Cr = +6$. Alternative (A) –2, represents the charge on the ion. Option (B), +3, is the charge on the Cr ion in the products. Choice (C) +5, would be the total charge on the two Cr atoms if the ON of O were –1.

The correct answer is (D).

[LO 3.8 SP 6.1]

4. In order to balance the seven O atoms in $Cr_2O_7^{2-}$, seven H_2Os are required, which leads to 14 H^+ ions. Alternative (A) 5, is the number of H^+ ions needed on the left to balance the charges in the half-reaction but does not balance the O atoms in $Cr_2O_7^{2-}$. Selection (B) 8, would be the number of H^+ ions needed to balance the charges when 2 Cr^{3+} ions are placed on the right side of the equation. Choice (C) 12, would be the number of H^+ ions needed if six H_2O molecules appeared on the right.

The correct answer is (D).

[LO 3.8 SP 6.1]

5. When the equation is balanced for O and H atoms the result is $Cr_2O_7^{2-} + 14\ H^+ \rightarrow 2\ Cr^{3+} + 7\ H_2O$. Six electrons would be needed on the left. Alternative (A) 4 on the right would be the number needed to balance the charges in the half-reaction in its current unbalanced form. Selection (B) 8 on the right, would be correct to balance the charges of the $Cr_2O_7^{2-}$ and 2 Cr^{3+} ions without regard for the H^+ ions needed. Choice (C) 12, is the number of electrons needed to balance 14 H^+ ions without regard to the 2 Cr^{3+} ions.

The correct answer is (D).

[LO 3.8 SP 6.1]

6. An oxidation-reduction reaction requires a change in oxidation numbers. Option (A) shows an acid-base reaction in which H^+ ions (from HCl) react with CO_3^{2-} ions in $Na_2CO_3(s)$ to form $CO_2(g)$ and $H_2O(l)$. There are no changes in oxidation numbers. In (B) Zn is changed to $ZnCl_2$ and HCl is converted to H_2, both of which represent changes in oxidation numbers. Choice (C) is a precipitation reaction in which Cl^- ions (from HCl) and Ag^+ ions (from $AgNO_3$) react to form solid AgCl. Selection (D) is an acid-base reaction in which a proton is transferred from gaseous HCl to gaseous NH_3 to form solid NH_4Cl.

The correct answer is (B).

[LO 3.8 SP 6.1]

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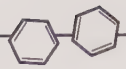

7. Equation (A) is shown in molecular form. Equation (B) shows Fe^{2+} being oxidized to Fe^{3+} but doesn't contain a reduction product. In addition, all of the ions (even spectator ions) are shown. In (C) Fe^{2+} is oxidized to Fe^{3+} and NO_3^- is reduced to NO. The charges and the atoms are both balanced as well. Selection (D) shows NO as N^{2+}, not the true chemical species although the charges and atoms are balanced.

   The correct answer is (C).

   [LO 3.2 SP 1.5]

8. Alternative (A), N_2, can undergo both reduction to form species such as NH_3, NH_2OH, or Li_3N and oxidation to give species such as NO, NO_2 or HNO_3. Option (B), NH_3, has nitrogen in its lowest formal oxidation state. Thus, it can potentially undergo oxidation to a variety of compounds and ions with higher oxidation states. Choice (C), N_2O_5, shows nitrogen in the +5 oxidation state, its maximum oxidation state that cannot be oxidized further. The oxidation number for N in $NaNO_2$ is +3 from $0 = +1 + ON_N + 2(-2)$ so it can be oxidized further to give +5 nitrogen.

   The correct answer is (C).

   [LO 3.2 SP 1.5]

9. The volume of $KMnO_4$ (or MnO_4^-) needed to react with the stated amount of H_2O_2 can be determined by first calculating the number of moles of H_2O_2:

$$(0.010\ \text{L})((0.200\ M) = 0.0020\ \text{mol}\ H_2O_2$$

   This can be converted to moles of MnO_4^- by using the balanced equation:

$$2\ \text{mol}\ MnO_4^-/5\ \text{mol}\ H_2O_2 = 8.0 \times 10^{-3}\text{mol}\ MnO_4^-$$

   The volume of 0.0100 M MnO_4^- can be obtained by dividing the moles by the molarity:

$$8.0 \times 10^{-3}\text{mol}\ MnO_4^-/0.0100\ M = 0.080\ \text{L}\,(80.0\ \text{mL})$$

   Alternative (A) 20.0 mL results from disregarding the MnO_4^-/H_2O_2 ratio. Choice (C), 200.0 mL, could be obtained by disregarding the MnO_4^-/H_2O_2 ratio and making an arithmetic error. Option (D), 500.0 mL, comes from inverting the MnO_4^-/H_2O_2 ratio.

   The correct answer is (B).

   [LO 3.4 SP 2.2]

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10. Sn^{2+} loses two electrons when it forms Sn^{4+} and Mn gains five electrons in changing from MnO_4^- to Mn^{2+}. In order for the electron loss to equal the electron gain requires five Sn^{2+}/two MnO_4^-. Alternative (A) 1/2 is the Sn^{2+}/MnO_4^- ratio if the two ions were to form a neutral compound but does not represent the ratio in which they would react in a redox reaction. Choice (B), 2/3, is the result if the Mn atom were to gain three electrons in going from MnO_4^- to Mn^{2+}. Option (D), 7/2, is the ratio of the oxidation numbers of Mn (in MnO_4^-) and Sn^{2+} in the reactants.

The correct answer is (C).

[LO 3.4 SP 2.2]

11. The anode is defined as the electrode at which oxidation occurs in both electrolytic and galvanic cells, not in one type of cell vs the other. Oxidation occurs with the loss of electrons, whether from an element to form a cation or from an anion to form an element. In either case, there will be an excess of electrons at the anode. Thus the cathode will be where reduction occurs, which involves the gaining of electrons. Electrons will flow from the anode to the cathode in both types of cells, alternative (A). Option (B), from the cathode to the anode in both types of cells, is the reverse. Choices (C) and (D) each have the direction of flow reversed in the two types of cells.

The correct answer is (A).

[LO 3.13 SP 5.1]

12. As written, the equations represent reduction processes that reflect the relative tendencies to gain electrons. With the higher reduction potential (+0.769 V), Fe^{3+}, choice (C), has the greater tendency to gain electrons with Cu^{2+} (+0.337 V), alternative (A), next. In order to identify the species that will release electrons most readily, the reverse processes (oxidation) and their potentials must be considered. When the equations are reversed the signs of the potentials change. The potentials for the oxidation reactions will be −0.337, Cu, option (B) and −0.769, Fe^{2+}, selection (D). While the negative signs for these potentials indicate that neither species is a robust electron donor, the one that is more likely to do so is the one with the less negative potential, Cu.

The correct answer is (B).

[LO 3.12 SP 2.2]

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13. The galvanic cell reaction is the spontaneous reaction, i.e. the one with the positive potential, that can be written from the half-reactions listed. The two reduction potentials cannot be added because a galvanic cell requires both an oxidation and a reduction process. Therefore, one of the reduction reactions listed must be reversed with a change in the sign of the potential before adding them, while giving a positive value. In order to meet these goals, the $Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$ half-reaction should be reversed, changing its potential to −0.337 V. (If the $Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$ were reversed, its potential would be −0.769 V and its sum with +0.337 V would be negative, resulting in a nonspontaneous reaction.) The sum of −0.337 and +0.769 V = +0.432 V, alternative (A). Option (B), +1.106 V, is the result of adding the two reduction potentials without reversing one of them. Choice (C), +1.201 V, results from doubling the reduction potential for $Fe^{3+}(aq)$, +0.769 V to +1.538 and adding the oxidation potential for Cu(*s*), −0.337 V, to it. Selection (D), +1.875 V, is the result of adding the reduction potential for $Cu^{2+}(aq)$, +0.337 to two times the reduction potential for $Fe^{3+}(aq)$, +0.769 V, to give +1.538 V.

The correct answer is (A).

[LO 3.12 SP 2.2]

14. Spontaneous reactions result from combining a reduction half-reaction with an oxidation half-reaction to give a positive potential. This can be achieved by adding the $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ half reaction ($E^\circ = +0.337$ V) with the reverse of the three half reactions above it to give potentials of +0.619 V ($Cu^{2+}(aq)$ + Co(*s*)), +0.673 V ($Cu^{2+}(aq)$ + Tl(*s*)), and 0.739 V ($Cu^{2+}(aq)$ + Cd(*s*)). In addition, when the $Co^{2+}(aq) + 2e^- \rightarrow Co(s)$ half reaction is combined with the two reversed half reactions above it potentials of +0.54 V ($Co^{2+}(aq)$ + Tl(*s*)) and 0.120 V ($Co^{2+}(aq)$ + Cd(*s*)) and when the $Tl^+(aq) + e^- \rightarrow Tl(s)$ half-reaction is added to the reverse of the $Cd(s) \rightarrow Cd^{2+}(aq) + 2e^-$ half-reaction which would have a potential of +0.066 V. Any combinations other than these would have negative potentials and would not be spontaneous. Thus there are a total of six spontaneous reactions. Alternative (A), 3 only, is the number of spontaneous reactions involving $Cu^{2+}(aq)$ only. Option (B), 4 only, could be the number of spontaneous reactions for $Cu^{2+}(aq)$ and the one involving $Tl^+(aq)$. Selection (D), 12, includes the six spontaneous reactions and the six non-spontaneous ones.

The correct answer is (C).

[LO 3.12 SP 6.4]

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15. In order to reduce Co^{2+} but not Cd^{2+}, the sign of the overall reaction must be positive in the first case but negative in the second. Of the choices given, Tl(s) will reduce $Co^{2+}(aq)$ because adding the potential for the $Co^{2+}(aq) + 2\,e^- \rightarrow Co(s)$ half-reaction (−0.282 V) to the reverse of the $Tl^+(aq) + e^- \rightarrow Tl(s)$ (−0.336 V) will give a positive potential whereas combining the $Cd^{2+}(aq) + 2\,e^- \rightarrow Cd(s)$ half-reaction ($E^\circ = -0.402$ V) with the reverse of the $Tl^+(aq) + e^- \rightarrow Tl(s)$ (−0.336 V) will give a negative potential. Alternative (A), $Cu^{2+}(aq)$, will not reduce either species because it cannot lose electrons. Selection (B), Cu(*s*), with an oxidation potential of – 0.337 V can reduce neither $Co^{2+}(aq)$ nor $Cd^{2+}(aq)$ because the combination of the Cu(*s*) half-reaction with the other two reduction half-reactions will result in negative potentials. Choice (C), $Tl^+(aq)$ has Tl in its oxidized form so, like $Cu^{2+}(aq)$, it cannot lose additional electrons.

The correct answer is (D).

[LO 3.12 SP 6.4]

16. The E° values for each of the choices given can be obtained by adding the potentials for the corresponding reduction and oxidation half-reductions. For alternative (A), the negative of the potential for the half-reaction, $Tl^+(aq) + e^- \rightarrow Tl(s)$, −0.336 V, would be added to the reduction potential for the half-reaction, $Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$, +0.337 V. The result would be +0.673 V. In selection (B), the potentials for the oxidation and reduction half-reactions $Tl(s) \rightarrow Tl^+(aq) + e^-$ and $Cd^{2+}(aq) + 2\,e^- \rightarrow Cd(s)$ would be added to give −0.066 V signifying a non-spontaneous reaction. Choice (C) would involve adding the reduction potential for $Cu^{2+}(aq)$, +0.337 V, to the oxidation potential for Cd(*s*), +0.402 V, to give +0.739 V. In selection (D), the reduction potential for $Cd^{2+}(aq)$, −0.402 V, to the oxidation potential for Cu(*s*), −0.337 V, to give −0.739 V. In general, the highest E° value will result from combining the two half-reactions with the greatest difference in SRPs after reversing the reaction for the more negative SRP.

The correct answer is (C).

[LO 3.12 SP 6.4]

17. Adding $SO_4^{2}(aq)$ to the half-reaction given will precipitate $PbSO_4$ and decrease the $[Pb^{2+}]$. According to LeChatelier's Principle this will shift the reaction toward the reactant and make the reaction less spontaneous (with E° more negative). The potential would not change, option (B), only if an added substance had no effect on either the reactants or products or affected both of them equally. Choice (C), it will change sign, would occur only if the reaction were shifted toward the products sufficiently to become spontaneous while option (D), it will become less negative, also represents a shift toward the products. Since $SO_4^{2-}(aq)$ does not react with Pb(*s*), its addition will not shift the half-reaction in this direction.

The answer is (A).

[LO 3.12 SP 6.4]

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18. The product formed at the anode will be the substance with the least negative oxidation potential and the product formed at the cathode will have the least negative reduction potential. For the anode reaction the reverse of the first two reactions should be considered while the cathode reaction comes from either of the latter two reduction processes as written. When reversed, the first half- reaction would result in the formation of $O_2(g)$ with a potential of -1.229 V. The second half-reaction to give $Br_2(l)$ would have a potential of -1.08 V. The product formed at the anode will be $Br_2(l)$ because it will require a smaller potential than the formation of $O_2(g)$. Thus neither answer (A) nor option (B) can be correct because they involve the formation of $O_2(g)$ at the anode. At the cathode, the reduction possibilities are $Ni(s)$, with a reduction potential of -0.25 V and $H_2(g)$, V $= -0.8277$ V. It will require a lower voltage to cause the deposition of $Ni(s)$ than to produce $H_2(g)$ and 2 $OH^-(aq)$. Choice (C) gives the formation of $Br_2(l)$ and $H_2(g)$ which cannot be correct.

The correct answer is (D).

[LO 3.13 SP 5.1]

19. The voltage of a cell will not be affected by changing the size of the electrodes, alternatives (A) and (D), because solids are not mentioned in LeChatelier's Principle and do not appear in an equilibrium expression or in the Nernst equation. Similarly, changing the volume of a solution, option (B), without altering its concentration has no effect on the potential of a reaction. Changing the concentration of the $Ag^+(aq)$ solution will affect the reaction and, because it appears as a reactant in this reaction, increasing its concentration will shift the reaction toward the products, increasing the voltage.

The correct answer is (C).

[LO 3.12 SP 6.4]

20. Reduction occurs in the cathode compartment of an electrochemical cell. Because the reaction shows $Ag^+(aq)$ ions being reduced to $Ag(s)$, this must be the process that occurs in the cathode compartment. When Ag^+ ions undergo reduction at the electrode, other Ag^+ ions will diffuse toward the electrode, alternative (A), rather than away from it, option (B). Cations would move away from the anode of an electrochemical cell where they would be produced by the oxidation of the metal electrode. Since $Cu(s)$ undergoes oxidation in this reaction, it would be present in the anode compartment rather than the cathode, eliminating choices (C) and (D).

The correct answer is (A).

[LO 3.13 SP 5.5]

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21. The equation that relates the free energy change (ΔG°) to the potential (and number of electrons) for an electrochemical reaction is $\Delta G^\circ = -nFE^\circ$. In this equation n is the number of moles of electrons transferred, F is the Faraday constant, (96,500 J/mol V), and E° is the cell potential. For $E^\circ = +0.460$ V and a transfer of 2 electrons, $\Delta G^\circ = -2(0.460)$ F. Alternative (A), (– 0.460)F, ignores the number of electrons. Option (B), (0.460)F, neglects both the number of electrons and the negative sign. Choice (C) includes the number of electrons but not the negative sign. Selection (D), – 2(0.460)F, gives the proper expression.

The correct answer is (D).

[LO 3.12 SP 5.4]

22. Because the aluminum ion has a +3 charge, the deposition of one mole of Al would require three moles of electrons. 0.600 moles of electrons can deposit 0.200 mol of Al. Alternative (A), 0.100, represents the number of moles of Al_2O_3 that could be reduced by 0.600 moles of electrons. Choice (C), 1.33 is the result of dividing the number of moles of Al_2O_3 by 3 and selection (D) is the product of the number of moles of electrons and the charge on the Al^{3+} ion.

The correct answer is (B).

[LO 3.12 SP 2.2]

23. Faraday's Lew's state that the quantity of a material produced by an electric current can be found by multiplying the amount of time (in seconds) by the current (in amperes). This value is divided by the Faraday constant (96,500 coul/mol e^-) to give the number of moles of electrons. The number of moles of electrons is then divided by the number of moles of electrons transferred per mole of substance produced.
2.50 coul/s × 2.00 h × 60 s/m × 60 m/h = number of coul.
number of coul/96,500 = mol e^-
mol Cu = mol e^-/2
Result is 2.50 coul/s × 2.00 h × 60 s/m × 60 m/h/96,500/2.0
Alternative (A) fails to convert hours to seconds or to include the charge on the Cu^{2+} ion. Choice (C) includes only one factor of 60 rather than two. Option (D) includes all of the necessary factors but multiplies by the atomic mass of Cu (63.54) thereby giving the mass of Cu deposited rather than the number of the moles.

The correct answer is (B).

[LO 3.12 SP 2.2]

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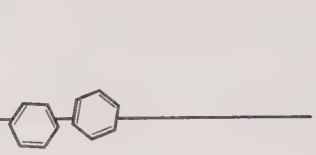

24. The number of electrons needed to deposit 1.27 g of Cu can be found by calculating the number of moles of Cu in 1.27 g (by dividing by the atomic mass, 63.54 g/mol). The number of moles of Cu is multiplied by the number of moles of electrons transferred per mole of Cu and by Avogadro's Number (Av. No.).
$1.27\ g\ Cu \times 1\ mol/65.34\ g \times 2\ mol\ e^- \times 6.022 \times 10^{23} e^-/mol = 2.4 \times 10^{22}$.
Alternative (A), 6.0×10^{21}, represents the number of moles of Cu divided by 2 and multiplied by Av. No. Option (B), 1.2×10^{22}, is the moles of Cu multiplied by Av. No. Selection (D), 4.8×10^{22}, includes an extra factor of 2.

The correct answer is (C).

[LO 3.12 SP 2.2]

25. Increasing the pH in reaction 1) will increase the reactant $[OH^-]$ so it will shift this reaction to the right. In reaction 2) increasing the pH decreases the $[H^+]$ in the reactants so it will shift the reaction toward the reactants. Increasing the pH in reaction 3) will lower the product $[H^+]$ so that will shift the reaction to the right. Alternative (A), 1 only, is not correct because it doesn't include reaction 3. Option (B), 2 only, is not correct because increasing the pH will shift the reaction to the left rather than the right. Selection (D), 1, 2, and 3, includes two reactions that will be shifted to the right but one that will be shifted to the left by an increase in pH.

The correct answer is (C).

[LO 3.12 SP 6.4]

26. The Nernst equation for this reaction includes the term $-(RT/nF) \ln [Ag^+]^3/[Au^{3+}]$. The cell potential, E, will be increased by raising $[Au^{3+}]$ or by decreasing [Ag+]. Alternative (A), doubling $[Au^{3+}]$ will have the effect of multiplying the denominator by 2. The ln term will be negative and, when multiplied by the $-(RT/nF)$ term will increase the cell potential. Option (B), doubling the $[Ag^+]$, will shift the reaction toward the reactants and lead to a decrease in the cell potential. Choice (C), cutting the $[Au^{3+}]$, will shift the reaction toward the reactants, decreasing the cell potential. Cutting the $[Ag^+]$ in half will cause a shift toward products, increasing the cell potential. Because the $[Ag^+]$ is raised to the third power in the Nernst equation, this is equivalent to dropping the concentration of a single product to 1/8 of its value. The ln term (−2.07) is three times that for doubling the $[Au^{3+}]$, (−0.693).

The correct answer is (D).

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27. The E° value of 0.00 V is the value for $[H_3O^+] = 1.00\ M$. The lower $[H^+]$, $1 \times 10^{-7}\ M$, in a solution with pH = 7.00, will cause a shift of the reaction toward the reactants, giving a value of E that is less than that for E°. Mathematically,

$$E = 0.00 - (0.0257/2) \ln [1]/[10^{-7}]^2,$$
$$E = 0.00 - (0.0257/2) \ln [\text{prod}]/[\text{reac}]$$
$$E = 0.00 - (0.0257)(16.12)$$
$$E = -0.414\ \text{V}$$

Option (B), −0.207 V, is obtained by omitting the factor of 2 in the denominator of RT/nF. Choice (C), +0.207 V, omits the factor of 2 and has the wrong sign. Selection (D), +0.414 V, has the correct value but the incorrect sign.

The correct answer is (A).

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CONSTRUCTED-RESPONSE SOLUTIONS

1. (a) The $Cr^{3+}(aq) + 3\,e^- \rightarrow Cr(s)$ half-reaction must be reversed and multiplied by 2 to give a positive potential and gain 6 electrons. The $Ni^{2+}(aq) + 2\,e^- \rightarrow Ni(s)$ half-reaction must be multiplied by 3 for a gain of 6 electrons so the electron loss will equal the electron gain.

$$2\,Cr(s) + 3\,Ni^{2+}(aq) \rightarrow 2\,Cr^{3+}(aq) + 3\,Ni(s)$$

The E° value is obtained by adding the half-reaction potentials after reversing one of them to give a positive potential for the overall reaction. (The E° values are not multiplied by the factors because they are intensive properties. Thus $0.744 - 0.236\ V = +0.508\ V$.)

(b) The cell can be drawn with the anode compartment on the left. For this reaction that is $Cr(s)$ to $Cr^{3+}(aq)$. The electrode is Cr metal and the solution is 1.0 M $Cr^{3+}(aq)$. The cathode involves the reduction of $Ni^{2+}(aq)$ to $Ni(s)$. The solution is 1.0 M $Ni^{2+}(aq)$ and the electrode is $Ni(s)$.

ii. A salt bridge must be used to connect the two solutions.

iii. Aqueous solutions are 1 M.

(c) $\Delta G^\circ = -nFE^\circ \qquad \Delta G^\circ = -6(96500)(0.508) \qquad \Delta G^\circ = -2.94 \times 10^5\ J$

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2. (a) The voltaic cell with the greatest potential would be constructed from the $Cd^{2+}(aq) + 2\,e^- \rightarrow Cd(s)$ and $Cu^{2+}(aq) + e^- \rightarrow Cu^+(aq)$ half-reactions, with the first of these being reversed to provide an oxidation reaction and a positive potential and the second multiplied by 2 to give 2 electrons.

$$Cd(s) + 2\,Cu^{2+}(aq) \rightarrow 2\,Cu^+(aq) + Cd^{2+}(aq)$$

(b) i. The potential will be $E^\circ = 0.402 + 0.161 \qquad E^\circ = +0.563$
The cell potential can be altered by increasing or decreasing $[Cu^{2+}]$, $[Cu^+]$, $[Cd^{2+}]$.

ii. Increasing $[Cu^{2+}]$ and decreasing $[Cu^+]$ and $[Cd^{2+}]$ will increase E° because these changes will shift the reaction toward the products. Decreasing $[Cu^{2+}]$ and increasing $[Cu^+]$ and $[Cd^{2+}]$ will decrease E° because these changes will shift the reaction toward the reactants.

(c) Current, time, and charge on the metal ion will all have an impact on the mass of metal deposited. Increasing the time and current will increase the mass of metal because more electrons will be transferred. If the metal ion has a higher charge a smaller mass of metal will be deposited because more electrons will be needed to reduce each metal ion.

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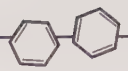

3. (a) To balance the reaction between IO_3^- and I^-, the half-reaction method can be used.

$$IO_3^- + 6\,H^+ + 5\,e^- \rightarrow 1/2\,I_2 + 3\,H_2O$$

$$I^- \rightarrow 1/2\,I_2 + e^-$$

After multiplying the second equation by 5 to cancel the number of electrons gained and lost, the result is

$$IO_3^- + 5\,I^- + 6\,H^+ \rightarrow 3\,I_2 + 3\,H_2O$$

(b) $3.56\text{ g } KIO_3 \times 1\text{ mol}/214\text{ g} = 0.0166\text{ mol } KIO_3 = 0.0166\text{ mol } IO_3^-$
$0.0166\text{ mol } IO_3^- \times 3\text{ mol } I_2/\text{mol } IO_3^- = 0.0498\text{ mol } I_2$

(c) $2\,Al + 3\,I_2 \rightarrow 2\,AlI_3$
$0.0498\text{ mol } I_2 \times 2\text{ mol } AlI_3/3\text{ mol } I_2 \times 407.7\text{g/mol} = 13.5\text{ g}$

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CHAPTER 12

WRITING NET IONIC EQUATIONS

1. A precipitation reaction with nitrate anion and potassium cation as spectator ions.

   $Pb^{2+} + CO_3^{2-} \rightarrow PbCO_3$

   [LO 2.15 SP 1.4, 6.2]

2. A precipitation reaction with chloride anion and sodium cation as spectators.

   $Sr^{2+} + SO_4^{2-} \rightarrow SrSO_4$

   [LO 2.15 SP 1.4, 6.2]

3. A precipitation reaction with nitrate anion and ammonium cation as spectator ions.

   $Ag^{+} + F^{-} \rightarrow AgF$

   [LO 2.15 SP 1.4, 6.2]

4. Both a precipitation reaction and a strong acid-strong base reaction.

   $Ba^{2+} + 2\,OH^{-} + 2\,H_3O^{+} + SO_4^{2-} \rightarrow BaSO_4 + 4\,H_2O$

   [LO 2.15 SP 1.4, 6.2] [LO 3.7 SP 6.1]

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5. A precipitation reaction with both nitrate anion and potassium cation as spectator ions.

   $3\,Ca^{2+} + 2\,PO_4^{3-} \rightarrow Ca_3(PO_4)_2$

   [LO 2.15 SP 1.4, 6.2]

6. A strong acid-weak base reaction with several variations of phosphate possible as a product.

   $H_3O^+ + PO_4^{3-} \rightarrow HPO_4^{2-} + H_2O$

   [LO 3.7 SP 6.1]

7. An acid-base reaction with no ambiguity about the products.

   $H_3O^+ + HPO_4^{2-} \rightarrow H_2O + H_2PO_4^-$

   [LO 3.7 SP 6.1]

8. A strong-acid-strong base reaction.

   $H_3O^+ + OH^- \rightarrow 2\,H_2O$

   [LO 3.7 SP 6.1]

9. An acid-base reaction.

   $NaH + H_2O \rightarrow Na^+ + OH^- + H_2$

   [LO 3.7 SP 6.1]

10. A redox equation of electrolysis of a fused salt.

    $2\,NaCl \rightarrow 2\,Na + Cl_2$

    [LO 3.12 SP 2.2, 2.3, 6.4]

11. A redox equation of electrolysis of an aqueous solution of a salt.

    $2\,Cl^- + 2\,H_2O \rightarrow 2\,OH^- + H_2 + Cl_2$

    [LO 3.12 SP 2.2, 2.3, 6.4]

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12. A redox equation of ions in acid solution.

$5\,SO_2 + 2\,H_2O + 2\,MnO_4^- \rightarrow 5\,SO_4^{2-} + 4\,H^+ + 2\,Mn^{2+}$

[LO 3.8 SP 6.1]

13. A redox equation of ions in basic solution.

$Cl_2 + 2\,OH^- \rightarrow Cl^- + ClO^- + H_2O$

[LO 3.8 SP 6.1]

14. A redox equation with iron starting at both ends of its range of oxidation numbers but finishing in the middle; a "disproportionation" reaction.

$Fe + 2\,Fe^{3+} \rightarrow 3\,Fe^{2+}$

[LO 3.8 SP 6.1

15. A weak acid-weak base reaction that leads to a Phantom.

$HC_2H_3O_2 + HCO_3^- \rightarrow C_2H_3O_2^- + H_2O + CO_2$

[LO 3.7 SP 6.1]

16. A weak acid-strong base reaction.

$OH^- + HPO_4^{2-} \rightarrow H_2O + PO_4^{3-}$

[LO 3.7 SP 6.1]

17. An acid anhydride-basic anhydride reaction to give a salt.

$CO_2 + K_2O \rightarrow K_2CO_3$

[LO 3.7 SP 6.1]

18. A redox equation, foretold by the elemental oxygen.

$C_2H_5OH + 3\,O_2 \rightarrow 2\,CO_2 + 3\,H_2O$

[LO 3.8 SP 6.1]

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19. A decomposition into ammonia gas and carbonic acid, which immediately decomposes into water and carbon dioxide.

$(NH_4)_2CO_3 \rightarrow 2\,NH_3 + H_2O + CO_2$

[LO 3.7 SP 6.1]

20. A decomposition reaction that forms oxygen gas.

$KClO_4 \rightarrow KCl + 2\,O_2$

[LO 3.8 SP 6.1]

21. A precipitation reaction deluxe.

$2\,OH^- + Cu^{2+} + Sr^{2+} + SO_4^{2-} \rightarrow Cu(OH)_2 + SrSO_4$

[LO 2.15 SP 1.4, 6.2]

22. A weak acid-strong base reaction that forms a Phantom.

$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$

[LO 3.7 SP 6.1]

23. A precipitation reaction.

$Ni^{2+} + S^{2-} \rightarrow NiS$

[LO 2.15 SP 1.4, 6.2]

24. A precipitation reaction.

$3\,Zn^{2+} + 2\,PO_4^{3-} \rightarrow Zn_3(PO_4)_2$

[LO 2.15 SP 1.4, 6.2]

25. A redox reaction of the complete combustion type.

$2\,C_3H_6 + 9\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$

[LO 3.8 SP 6.1]

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SAMPLE EXAMINATION 1

1. Oxidation numbers can be found from the relationship
   Ionic charge = [Ox. No. of element + number of Os $\times(-2)$]

carbonate = (CO_3^{2-})	$-2 = [C + 3(-2)]$	$-2 + 6 = C$	$C = +4$
chlorate = (ClO_3^-)	$-1 = [Cl + 3(-2)]$	$-1 + 6 = Cl$	$Cl = +5$
nitrite = (NO_2^-)	$-1 = [N + 2(-2)]$	$-1 + 4 = N$	$N = +3$
sulfate = (SO_4^{2-})	$-2 = [S + 4(-2)]$	$-2 + 8 = S$	$S = +6$

The correct answer is (D).

[LO 2.21 SP 1.4]

2. From the information in question 1, the lowest oxidation number is found in the nitrite ion.

The correct answer is (C).

[LO 2.21 SP 1.4]

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3. The only central atom that can be oxidized to the +7 oxidation state is Cl (in the ClO_4^- ion).

   The correct answer is (B).

   [LO 2.21 SP 1.4]

4. The oxidation number of N in nitrogen dioxide, NO_2, is
   $0 = [N + 2(-2)]$
   $0 + 4 = N$
   $N = 4$.
   The species with a + 4 oxidation state is the C in CO_3^{2-}.

   The correct answer is (A).

   [LO 2.21 SP 1.4]

5. With an electron configuration of $1s^2\ 2s^2\ 2p^1\ 2p^1\ 2p^1$, N has more unpaired electrons than any of the other three atoms, each of which has one unpaired electron.
   (Li $1s^2\ 2s^1$)
   (B $1s^2\ 2s^2\ 2p^1$)
   (F $1s^2\ 2s^2\ 2p^2\ 2p^2\ 2p^1$)

   The correct answer is (C).

   [LO 1.9 SP 6.4]

6. IEs increase from left to right across the PT. This is due to the greater attractions felt by valence electrons as the effective nuclear charge increases. Of the elements listed F is furthest to the right and has the greatest effective nuclear charge and hence the highest IE.

   The correct answer is (D).

   [LO 1.9 SP 6.4]

7. The electron configurations given above in answer to q. 5 show that Li has a single valence electron. Further, by looking at a periodic table it is possible to conclude that all alkali metals (like Li) have a single valence electron that can be lost to form +1 ions.

   The correct answer is (A).

   [LO 1.9 SP 6.4]

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8. In PCl_5 the central atom P is surrounded by 5 Cl atoms. Because both of these elements are nonmetals the compound is a covalent compound and the bonds between the atoms are covalent bonds. From their positions in the periodic table the electronegativity of Cl is greater than that of P so the covalent bonds must be polar.

   The correct answer is (D).

   [LO 2.32 SP 1.1]

9. The alloy brass consists of the metals copper and zinc. The bonds in alloys are metallic bonds.

   The correct answer is (B).

   [LO 2.27 SP 1.1]

10. Ammonium chloride consists of the NH_4^+ ions, each of which is held together by covalent bonds, and chloride ions, Cl^-. It is an ionic solid with an ionic bond between the ammonium ion, NH_4^+, and the chloride ion, Cl^-.

    The correct answer is (A).

    [LO 2.23 SP 1.1]

11. Nitrogen is a nonmetal so two nitrogen atoms will be bonded to one another by covalent bonds. Since the atoms are the same (with the same electronegativities) the bonds will be non-polar covalent bonds.

    The correct answer is (C).

    [LO 2.32 SP 1.1]

12. A substance that oxidizes other substances must undergo reduction itself. The most common oxidizing substances are elements in high oxidation states in their compounds that will readily gain electrons. Of the substances given potassium permanganate is the best oxidizing substance. In phosphoric acid P is in its highest oxidization state but has little tendency to gain electrons. Methylamine and zinc(II) hydroxide do not oxidize other materials.

    The correct answer is (B).

    [LO 3.8 SP 6.1]

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13. An amphoteric substance is one that can react with either an acid or base. Of the substances listed zinc(II) hydroxide is the only substance that can do this as indicated by the equations: $Zn(OH)_2 + 2\,H^+ \rightarrow Zn^{2+} + 2\,H_2O$ or $Zn(OH)_2 + 2\,OH^- \rightarrow Zn(OH)_4^{2-}$

The correct answer is (D).

[LO 3.7 SP 6.1]

14. Of the substances listed the only one that is colored is potassium permanganate.

The correct answer is (B).

[LO 3.8 SP 6.1]

15. According to the Table, metal III is a yellowish solid that does not react with either HCl or HNO_3. Silver, Ag, and zinc, Zn, are both silvery in appearance but copper, Cu , and gold, Au, are both yellowish solids. Cu does not react with HCl but does react with HNO_3. Therefore, metal III cannot be Cu. Au does not react with either HCl or with HNO_3. (A mixture of HCl and HNO_3, called aqua regia, is needed.)

The correct answer is (B).

[LO 2.28 SP 1.1]

16. Brass is an alloy of Cu and Zn while bronze is an alloy of Cu and Sn. The ingredient that is common to both of these alloys is Cu.

The correct answer is (C).

[LO 2.28 SP 1.1]

17. A two-step reaction is one that will have two separate activation energies such as reaction profiles (B) and (D). If the second step is rate determining its activation energy must be greater than that for the first step.

The correct answer is (D).

[LO 4.6 SP 1.4]

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18. The change in reaction rate is directly related to the activation energy. The larger the activation energy is the greater the change in rate. (This can be shown by considering a reaction with an activation energy of zero, which will be equally fast at all temperatures.) Of the reaction profiles shown the largest activation energy is shown for choice (A).

    The correct answer is (A).

    [LO 4.6 SP 1.4]

19. Reaction intermediates are found in multi-step reactions in which the intermediate is produced in one step of the reaction and is consumed in a later step. Reaction profiles (B) and (D) both involve reaction intermediates, indicated by the valley between the activation energy peaks. The deeper this valley is, the more stable the intermediate.

    The correct answer is (D).

    [LO4.7 SP 6.5]

20. Reaction intermediates are found in multi-step reactions in which the intermediate is produced in one step of the reaction and is consumed in a later step. In the reaction mechanism shown the only substance that is produced in the first step and consumed in the second step is NO_3 so this must be the intermediate.

    The correct answer is (C).

    [LO 4.7 SP 6.5]

21. If the second step is the rate-determining (i.e. slow step), the rate equation for that elementary step is Rate $= k[CO][NO_3]$. If the first step of this reaction is rate-determining the rate equation is Rate $= k[NO_2][NO_2]$ or Rate $= k[NO_2]^2$, which does not contain a term in [CO].

    The correct answer is (D).

    [LO4.7 SP 6.5]

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22. If the first step of this reaction is rate-determining, the rate equation is Rate = $k[NO_2][NO_2]$ or Rate = $k[NO_2]^2$. If the second step is the rate-determining, the rate equation for that elementary step is Rate = $k[CO][NO_3]$ and the first step must be a fast equilibrium, $K = [NO_3][NO]/[NO]^2$. The intermediate NO_3 in the second step can be replaced by solving the equilibrium expression to give $[NO_3] = K[NO_2]^2/[NO]$. Thus, the overall rate equation is Rate = $kK[CO][NO_2]^2/NO$. NO_2 appears in the rate equation regardless of which step is rate-determining.

The correct answer is (B).

[LO 4.7 SP 6.5]

23. The potential energy at the boiling point is converted to work energy in overcoming attractive forces between molecules, so that they may escape in the gas phase (V). This is a larger amount of energy than solid molecules need to overcome attractions to enter the liquid phase where molecules are still in some contact with one another.

The correct answer is (C).

[LO 5.6 SP 2.2, 2.3]

24. Kinetic energy is directly related to the temperature of a system. The change in temperature from 0°C to 100°C is larger than that from −50°C to 0°C or that from 100°C to 110°C.

The correct answer is (B).

[LO 5.6 SP 2.2, 2.3]

25. Entropy increases when there is an increase in disorder in a system. Such an increase in disorder occurs with an increase in temperature of a given phase and when a more organized phase is changed to a less orderly one. All five areas of the curve represent increases in entropy but Section IV (the transformation of liquid to gas) will show a greater change in ΔS than the increase in temperature of solid H_2O (section I), the conversion from solid to liquid (section II), the increase in temperature of liquid H_2O (section III) or the increase in temperature of gaseous H_2O (section V).

The correct answer is (C).

[LO 5.6 SP 2.2, 2.3]

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26. The following calculation would give a heat of solution of +35.1 kJ:
$-(100 \times -8.4^{\circ}C \times 4.18\ J/g^{\circ}C) = 3510$ J per 10.1 g of KNO_3 dissolved. When converted to kJ per mole, that would equal +35.1 kJ/mol. The enthalpy change is included on the reactant side of the equation to show the endothermic nature of the reaction.

The correct answer is (A).

[LO 5.7 SP 4.2, 5.1]

27. The heat involved is directly related to the amount of reactant, thus both ΔT and J per reaction will be larger. The other table entries are ratios of heat/amount that will stay the same for the same reason.

The correct answer is (C).

[LO 5.7 SP 4.2, 5.1]

28. The [HA] and $[A^-]$ will be equal to one another when one half of the acid has been neutralized. This occurs halfway between the beginning of the titration and the steeply rising portion of the curve, which signals the neutralization point. Point II represents the point where $[HA] = [A^-]$.

The correct answer is (B).

[LO 6.3 SP 5.1]

29. The point with the highest electrical conductivity is the point where all of the acid has been converted from the molecular HA form to A^- ions and there is an excess of Na^+ and OH^- ions. This occurs at point IV.

The correct answer is (D).

[LO 6.3 SP 5.1]

30. The equivalence point is the point where the number of moles of NaOH added is equal (i.e. equivalent to) the number of moles of HA originally present. This corresponds to the mid-point of the portion of the curve where the pH changes most rapidly (point III).

The correct answer is (C).

[LO 6.3 SP 5.1]

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31. The two gases are at the same temperature so their kinetic energies are equal. Thus (A) is correct. The masses of the two gas samples are the same but the volume of the O_2 sample is one half that of the SO_2 sample. The density of O_2 is double that of the SO_2. Statement (B) is correct. The molecular velocities of two gases at the same temperature are inversely related to the square roots of their molecular masses. The average molecular velocity of O_2 is greater than that of SO_2. (D) is correct. The equation PV = nRT would show that the pressure of O_2 is 4 × the pressure of the SO_2 sample, not twice as great as stated in (C).

The correct answer is (C).

[LO 2.6 SP 2.2, 2.3]

32. The PES diagram shows a single electron at about 1, six at an energy of ~3, two at energy of ~7 and two at an energy above 100. This would correspond to an electron configuration of $1s^2\ 2s^2\ 2p^6\ 3s^1$. There is one valence electron.

The correct answer is (A).

[LO 1.6 SP 5.1]

33. The number of moles of Na_2CO_3 can be calculated from 0.212 g/106 g mol^{-1} = 0.00200 mol. According to the equation given, two moles of HCl are required for every mole of Na_2CO_3 so 0.004 moles of HCl are needed. The molarity of the HCl = 0.00400 mol/0.025 L. The molarity is 0.16 *M*.

The correct answer is (A).

[LO 3.4 SP 2.2]

34. A linear plot of [ ] vs time is not first order and a linear plot of 1/[ ] vs time is not zero order so choice (A) is not correct. A linear plot of ln [ ] vs time is first order and a linear plot of 1/[ ] vs time is second order so choice (B) is correct. A linear plot of [ ] vs time is not indicative of a second order reaction although a linear plot of ln[ ] vs time is found for a first order reaction. Choice (C) is not correct. In choice (D), a linear plot of [ ] vs time is obtained for a zero order reaction but a first order reaction does not show a linear plot when 1/[ ] is plotted vs time. Choice (D) is not correct.

The correct answer is (B).

[LO 4.2 SP 5.1]

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35. The process is thermodynamically favored, hence $-\Delta G$. It is endothermic as indicated by the 6.0 kJ on the reactant side of the equation, hence ΔH is +. The process leads to a more random collection of molecules, hence ΔS is +.

The correct answer is (A).

[LO 5.13 SP 2.2, 2.3, 6.4]

36. Formula stoichiometry requires a 3:1 ratio between moles/L of Al^{3+} and NO_3^- ions as in $Al(NO_3)_3$ but $Al(NO_3)_3$ ionizes in H_2O so choice (A) is not correct. Choice (B) is not correct because the mole ratio is not right, which is also the case for choice (D). Choice (C) has the correct 3/1 ratio for NO_3^-/Al^{3+} ions.

The correct answer is (C).

[LO 2.9 SP 1.1, 1.4]

37. The mass of the quantity of ZnS from weighed quantities of Zn and S can be used to illustrate the Law of Constant Composition, choice (A), because a specific mass of Zn reacts with a specific mass of S. It illustrates the Law of Conservation of Mass, choice (B), because the mass of the product is the same as the masses of the reactants. It illustrates the Law of Definite Proportions, choice (C) because Zn and S react with one another in a 1:1 ratio. It does not show the Law of Multiple Proportions, Choice (D), because only a single compound is formed between Zn and S.

The correct answer is (D).

[LO 3.5 SP 2.1]

38. If reaction 2 is reversed and added to reaction 1, the result will be reaction 3. The free energies then may be added up: $+86.2 + (-300.1) = -213.9$ kJ. The negative value for ΔG° signifies that the K_{eq} favors products and that copper can be extracted via reaction 3.

The correct answer is (C).

[LO 5.15 SP 6.2]

39. Acid strength increases with the number of Os because free Os in the structure draw bonding electrons from the H–O bond and release the H more readily. Thus $HOClO_3$ is the strongest acid and HOCl is the weakest. The weakest acid will require the highest concentration and the greatest number of moles of acid to achieve the specified pH.

The correct answer is (A).

[LO 6.12 SP 1.4]

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40. Nitric acid, HNO_3, oxidizes other materials by undergoing reduction itself. It does not produce Cl_2, choice (A), as there is no Cl in HNO_3. It does not form H_2, choice (B), which is only produced by substances that do not contain more reducible portions, such as NO_3^-. It does form colorless NO, choice (C), initially but when NO comes into contact with air, it is converted to brown NO_2 as is typically observed in the laboratory.

The correct answer is (D).

[LO 3.8 SP 6.1]

41. All of the choices listed involve electrons moving from higher levels to lower ones so all of them will emit energy. The light emitted by an electron that falls from n = 6 to n = 1, choice (A), would appear in the UV portion of the spectrum. An electron that drops from n = 5 to n = 4, option (B), would emit radio waves. The electron transition from n = 4 to n = 2, choice (C), occurs in the visible. The transition n = 4 to n = 3, choice (D), appears in the infrared region.

The correct answer is (C).

[LO 1.6 SP 5.1]

42. An increase in boiling points observed for nonpolar molecules such as halogens is due to an increase in intermolecular forces. Covalent bonds, option (A), are not involved and actually decrease descending the family rather than increasing as stated here. Intermolecular, dispersion forces strengthen as the molecules become larger due to an increase in polarizability, choice (B). Choice C is a true statement but is not the reason for the trend. Option (D) is incorrect as permanent dipole forces are not present.

The correct answer is (B).

[LO 2.11 SP 6.2, 6.4]

43. The percentage of $CaCO_3$ may vary from one limestone deposit to another, option (A), as may the ratio of the isotopes C-12 and C-14, selection (C), and their crystalline form selection (D). The one characteristic that is the same from one deposit to another is the mass ratio of the constituent atoms, alternative (B), in keeping with the Law of Definite Proportions.

The correct answer is (B).

[LO 1.1 SP 7.1]

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44. The reaction involves the transfer of an O atom from NO_2 to CO so that a successful collision should have a molecular orientation that makes this likely. Option (A), in which one of the Os of NO_2 is in contact with the C of CO, would promote that transfer. In alternative (B) an O in NO_2 is in contact with the O in CO, which would not facilitate the formation of a bond. Choices (C) and (D) involve contact between the N of NO_2 and either the C or the O of CO, which would not promote the desired O transfer.

The correct answer is (A).

[LO 4.4 SP 7.1]

45. At any temperature, the molecules in a collection are described as having a range of kinetic energies in keeping with the Maxwell Boltzman energy distribution but have an average kinetic energy, choice (B), rather than having a single energy, as stated in option (A). Selections (C) and (D) are incorrect statements, because the average kinetic energy change is proportional to the change in Kelvin temperature, and at 0 Kelvin, the average kinetic energy of the water molecules would fall to zero.

The correct answer is (B).

[LO 5.2 SP 1.1, 1.4, 7.1]

46. The ionization constants given indicate that ascorbic acid, $H_2C_6H_6O_6$, ionizes only slightly. The most abundant species will be the un-ionized acid, choice (A). The concentration of $HC_6H_6O_6^-$, option (B), will be about 1/100 of the acid, with the $[H^+]$, alternative (C), being slightly greater than $[HC_6H_6O_6^-]$, due to further ionization to form $C_6H_6O_6^{2-}$, selection (D), which will have the lowest concentration.

The correct answer is (A).

[LO 6.17 SP 6.4]

47. Hydrogen bonds are formed between an H atom attached to a highly electronegative atom (F, O or N) in one molecule and a lone pair of electrons on an electronegative atom in a nearby molecule. The H atoms in ethane, option (A), dimethyl ether, choice (C), and methyl fluoride, selection (D), are all attached to C atoms. Only ethanol, alternative (B), has a H atom attached to another atom (O) that would polarize the H and make it suitable for H bonding with an O on another molecule of ethanol.

The correct answer is (B).

[LO 2.13 SP 1.4]

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48. The best sacrificial anode would be the element with the most positive oxidation potential, which would be found by changing the sign of the reduction potential. When this is done the oxidation potentials for the four metals are +2.36 V (Mg), +0.12 V (Pb), −0.34 V (Cu) and −0.80 V (Ag). Mg(*s*) is the most reactive metal and would thus be more likely to give up electrons than any of the other metals.

    The correct answer is (D).

    [LO 3.12 SP 2.2, 2.3, 6.4]

49. The equation for the reaction in question can be obtained by adding the equation for reaction 1 to the reverse of the equation for reaction 2. $K = [N_2O_4]/[NO]^2[O_2]$ for the overall reaction. This can be obtained by multiplying K_1 by $1/K_2$, option (C).

    The correct choice is (C).

    [LO6.2 SP 2.2]

50. SiO_2, alternative (A), is a network solid that would not conduct electricity when it is melted. Ice, choice (B), and wax, selection (C), are molecular solids that would not conduct electricity when melted. Molten NaCl would consist of mobile anions and cations that would conduct electricity.

    The correct answer is (D).

    [LO 2.24 SP 1.1, 6.2, 7.1]

51. Points I, alternative (A), and III, choice (C), represent activated complexes and point IV, selection (D), represents the final product. Point II, choice (B), represents the reaction intermediate O(*g*) that is produced in the first reaction and consumed in the second.

    The correct answer is (B).

    [LO 4.7 SP 6.5]

52. If the two isotopes were equally abundant in a 1/1 ratio, alternative (A), the average atomic mass would be 36. If the ratio were 2/1, as in option (B), the average atomic mass would be 107/3 or 35.67. For a ratio of 3/1, selection (C), the average atomic mass would be $[3(35) + 37]/4$ or 35.5. For a ratio of 4/1, choice (D), the average atomic mass would be found from $[4(35) + 37]/5$ or $177/5 = 35.4$.

    The correct answer is (C).

    [LO 1.14 SP 1.4]

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53. If bubbles are being produced the system is not at equilibrium, alternative (A). The large negative ΔG° is indicative of a very large K_{eq}, not a very small one, choice (B). The production of oxygen gas would not shift the reaction toward the reactants as suggested in selection (C). The rate is slow because the reaction lacks the necessary activation energy as stated in choice (D).

The correct answer is (D).

[LO 5.18 SP 1.3, 7.2]

54. The pH of the blood is controlled by the $HCO_3^-(aq)$ / $H_2CO_3(aq)$ buffer so H^+ would not react with OH^-, alternative (A). Although OH^- could react with HCO_3^- as shown in choice (B) it would not do so in the presence of the stronger acid $H_2CO_3(aq)$. The weak acid in the system, H_2CO_3, reacts with most of the excess OH^- to produce HCO_3^-, thereby stabilizing the pH of the blood as in choice (C). It would not react as in selection (D).

The correct answer is (C).

[LO 6.20 SP 6.4]

55. In balancing the equation 2 Cr are formed. The three O in Cr_2O_3 react with three CO to form three CO_2.

The correct answer is (C).

[LO 3.2 SP 1.5]

56. The $[Ag^-]$ in saturated solutions of AgCl and AgSCN can be found by taking the square root of the K_{sp} values to give 1.3×10^{-5} and 2.8×10^{-6}, respectively. The $[Ag^+]$ in Ag_2CrO_4 is obtained by taking the cube root of $1/4 \times 10^{-12}$ to give a value a little greater than 6×10^{-5}. From smallest to largest, the order of these values is $AgSCN < AgCl < Ag_2CrO_4$, choice (B).

The correct answer is (B).

[LO 6.21 SP 2.2]

57. The dependence of spontaneity on temperature can be determined by using the equation; $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. When T is low the negative ΔH° will make ΔG° negative resulting in a spontaneous reaction. As the temperature increases the negative ΔS° will make the value of ΔG° less negative and eventually positive so the reaction will become non-spontaneous. Thus, the reaction will be spontaneous at low temperatures but become non-spontaneous at high temperatures.

The correct answer is (D).

[LO 5.13 SP 2.2]

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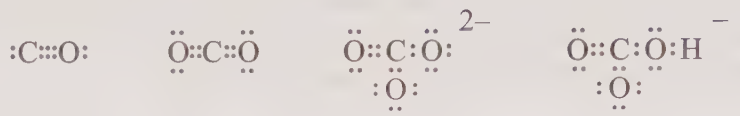
58. The Lewis dot structure for the four species are



Of these, the only one that has a lone pair of electrons on the carbon is CO.

The correct answer is (A).

[LO 2.21 SP 1.4]

59. At the given concentrations of 0.10 *M* for each species the value of Q, $\frac{[Cl_2]^2[H_2O]^2}{[H_4]^4[O_2]}$, will be 10, much greater than the value of 1.5 for K_c. Thus, the reaction will shift toward the reactants to reach equilibrium. The concentrations of H_2O and Cl_2 will decrease while those of HCl and O_2 will increase. The concentration of HCl(*g*), with a coefficient of 4, will increase more than that of O_2(*g*).

The correct answer is (A).

[LO 6.4 SP 2.2]

60. The student obtained a value for H_2O_2 that was too large so must have made an error that used too much $KMnO_4$ solution. If the student failed to rinse the buret with $KMnO_4$, choice (A), the solution in the buret would be more dilute than it was thought to be. More solution would be required to reach the equivalence point and the number of moles of H_2O_2 would be too large. If the student stopped short of the endpoint, option (B), the value would be too low, not too high. The addition of extra H_2O to the titration flask, as in alternative (C), would have no effect on the results. Failing to wear goggles, selection (D), would create an unsafe situation but would not affect the results.

The correct answer is (A).

[LO 3.3 SP 2.2, 5.1]

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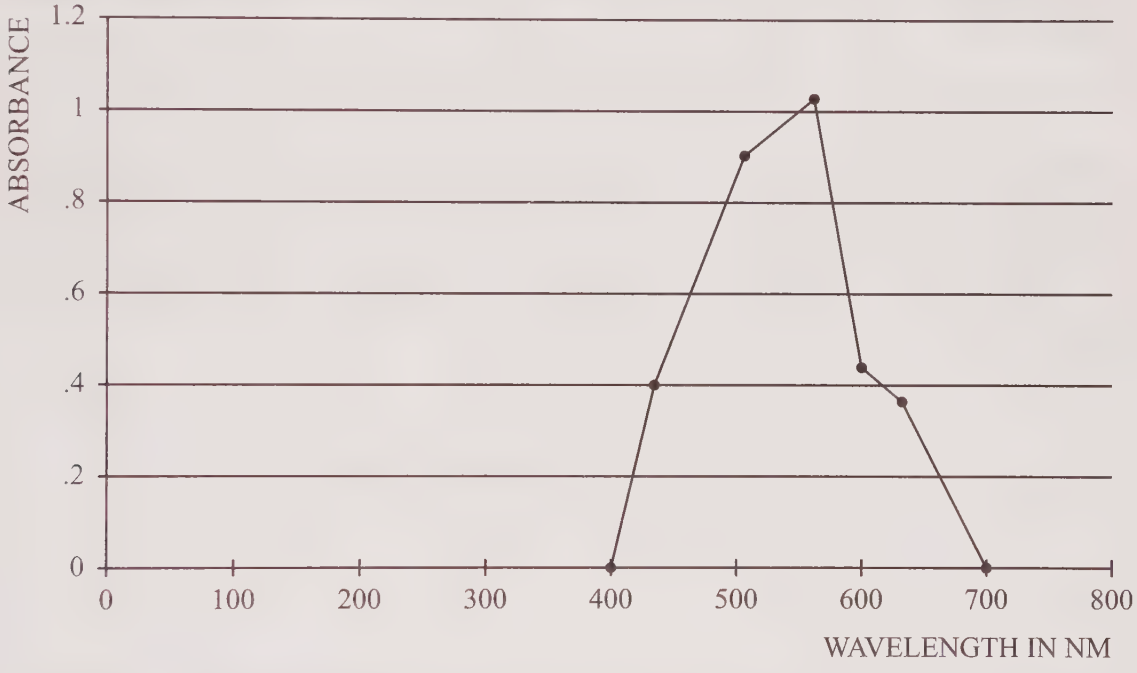
CONSTRUCTED-RESPONSE SOLUTIONS

Question 1 (Big Idea 1 spectroscopy)

1. (a) $\nu = c/\lambda = (2.998 \times 10^8 \text{ m/s}) / (650 \times 10^{-9} \text{m}) = 4.62 \times 10^{14}/\text{s}$

   (b) $E = hc/\lambda = (6.626 \times 10^{-34} \text{J s})(2.998 \times 10^8 \text{m/s}) / (650 \times 10^{-9} \text{m}) = 3.06 \times 10^{-19} \text{J}$

2. (a) Sketch of absorbance curve:



   (b) The permanganate anion absorbs in the yellow but reflects everything else. The apparent color (purple) is a combination of those reflected wavelengths.

3. (a) $2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$

   (b) The function of the concentration that would give a straight line would be ln $[N_2O_5]$ vs t. The slope of that line is equal to $-k$, the rate constant.

   (c) From the Arrhenius equation: $\ln(k_2/k_1) = (E_a/R)(1/T_1 - 1/T_2)$. In order to avoid unit errors, be sure that all temperatures used are expressed in absolute temperature (Kelvins) and that all energy values are expressed in kJ. No calculation is necessary but the data show that a greater number of collisions are effective (have E_a needed to reach the transition state) at the higher temperature. For interpretation of graphs, the slope of the line plotting ln k vs. 1/T equals E_a/R

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Question 2 (Big Idea 2 interparticulate interactive forces)

1. As the number of electrons increases, so does polarizability. These temporary dipoles thus formed lead to greater attractive forces and therefore higher boiling points.

2. As the number of electrons around each homonuclear diatomic molecule increases, so does the possibility of more pronounced temporary dipoles, thus leading to greater interparticulate attractive forces and higher boiling points.

3. As an increasing number of electrons are arranged around these non-polar molecules, greater temporary dipoles can occur. Thus there are greater attractive forces between these temporary dipoles, leading to higher boiling points.

4. (a) More electrons lead to greater temporary dipoles and greater attractive forces.

   (b) The permanent dipole in the NO molecule means greater attractive forces than the temporary dipoles formed in either elemental species.

   (c) NO is more polar than CO so the permanent dipole attractions between NO molecules are greater.

5. The column containing information about water should be circled. Each molecule among hydrogen sulfide, hydrogen selenide, and hydrogen telluride populations is attracted to its neighbors by London forces and, since each molecule is polar, by dipole forces. Only water adds hydrogen bonding to its list of attractive forces. Hydrogen bonding, although not a bond, is a much more pronounced interparticulate attraction so the boiling point of water is much higher than expected in the other molecules.

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Question 3 (Big Idea 3 lab question)

1. A primary standard is a substance of known formula and purity. Knowing the quantity of a primary standard (mass or volume of known solution) allows comparison of some other reactant's mass or volume to ascertain the quantity of the reactant.

2. (a) The number of moles of FAS is tracked by the mass of the solid, not by the volume of solution. So the actual volume of distilled water added to the FAS does not matter.

   (b) Since the number of moles of electrons exchanged in the oxidation and reduction halves of the redox reaction must be the same, the ratio of Fe^{2+} to MnO_4^- must be 5:1.

   (c) $0.919\text{ g FAS} \times (1\text{ mol FAS}/392.13\text{ g FAS}) \times (1\text{ mol } MnO_4^-/5\text{ mol } Fe^{2+}) = 0.000469\text{ mol } MnO_4^-$
   $(0.000469\text{ mol } MnO_4^-/0.02107\text{ L}) = 0.0222\ M\ MnO_4^-$ solution

3. (a) $(0.0208\text{ L} \times 0.0112\ M\ MnO_4^-)(5\text{ mol } Fe^{2+}/1\text{ mol } MnO_4^-)(55.85\text{ g Fe}/1\text{ mol Fe}) = 0.0651\text{ g Fe}$

   (b) $(0.0651\text{ g Fe}/0.385\text{ g tablet}) \times 100\% = 16.9\%\text{ Fe}$

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Question 4 (Big Idea 3)

(a) i. $H_3O^+ + OH^- \rightarrow 2\,H_2O$
OR $H^+ + OH^- \rightarrow H_2O$

ii. Bromthymol blue is the best choice since its color change occurs around the target pH = 7. In practice, any one of the indicators would work since the pH change on the titration curve describing the titration is so rapid near the equivalence point.

(b) i. $HC_2H_3O_2 + OH^- \rightarrow H_2O + C_2H_3O_2^-$

ii. Phenolphthalein is the best choice since it changes in basic solution. The acetate anion, which remains in solution at the equivalence point after the reaction of the strong base with the weak acid, is a basic anion. The hydrolysis reaction of this basic anion is $C_2H_3O_2^- + H_2O \rightarrow HC_2H_3O_2 + OH^-$.

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Question 5 (Big Idea 4 Kinetics)

(a) The average kinetic energy of a population of particles increases with absolute temperature. Therefore there are more collisions between particles, leading to more reactions even if the fraction of effective collisions remains the same. The collisions also occur between particles carrying greater kinetic energy so more of them will carry sufficient energy to break old bonds and allow new bonds to form, a description of the activation energy.

(b) i. $2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$

ii. If the pressure of the N_2O_5 falls to 0.80 atm, then by stoichiometry 0.20 atm must have reacted to form 0.40 atm NO_2 and 0.10 atm O_2. The new total pressure is then $(0.80 + 0.40 + 0.10) = 1.3$ atm.

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Question 6 (Big Idea 5 thermodynamics)

(a) The energy transferred from boiling water to the skin of the victim is losing energy within the liquid phase, a relatively small amount. As steam changes from gas to liquid, it must release the energy called the heat of vaporization, a much larger quantity, thereby causing a much more severe burn.

(b) i. $CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(g)$

ii. $Q = mc\Delta T = (250\text{ g})(4.184\text{ J/g°C})(53°C) = 55{,}438\text{ J}$
$\text{Mol } CH_4 = 1.00\text{ g } CH_4 \times (1\text{ mol } CH_4/16.05\text{ g}) = 0.0623\text{ mol}$
$\Delta H = (55.438\text{ kJ})/(0.0623\text{ mol}) = -890\text{ kJ/mol}$ (negative since heat is released)

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Question 7 (Big Idea 6 equilibrium)

7. (a) Adding N_2O_4 will cause a shift to the left (reactants) to consume some of the added N_2O_4 product. Greater collision frequency between N_2O_4 molecules will result in the formation of more NO_2 molecules.

(b) Removing NO_2 will cause a shift to the left (reactants) to restore some of the removed NO_2 reactant. The reverse reaction which forms NO_2 continues at the same rate initially upon the removal of some NO_2 but the collision frequency between reactant NO_2 molecules will decrease, resulting in a net build-up of NO_2.

(c) Increasing the volume will cause a shift to the left (reactants) to restore some of the relieved pressure. Collision frequency decreases between NO_2 molecules in a larger volume.

(d) Reverse the first equation and invert its K value.
Leave the second equation as is.
Multiply the third equation by 2 and square its K value.
The three equations will now add to $N_2O + 3/2\ O_2 \longleftrightarrow N_2O_4$ so the three K values may be multiplied to reach an overall K.
Thus $1/K_1 \times K_2 \times K_3^2 = (2.9 \times 10^{17})(2.2 \times 10^{2})(1.7 \times 10^{-17}) = 1.1 \times 10^{3}$

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SAMPLE EXAMINATION 2

1. The distribution of electrons within the n = 3 level are $3s^2\ 3p^6\ 3d^{10}$. The 3*s* sublevel is being filled with groups I and II, Na and Mg. The 3*p* fills for the elements Al–Ar. The first transition series involves the filling of the 3*d* sublevel for the elements Sc–Zn. The 3*d* sublevel ends in the transition series.

   The correct answer is (C).

   [LO 1.9 SP 6.4]

2. See the description of the various sublevels in question 1. All *p* sublevels end with noble gases and the 3*p* sublevel is completed with the noble gas Ar.

   The correct answer is (B).

   [LO 1.9 SP 6.4]

3. Colored solutions result when unpaired electrons in the 3*d* sublevel become excited through the absorption of visible light and release energy when they drop back down to lower energy levels.

   The correct answer is (C).

   [LO 1.9 SP 6.4]

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4. As stated in the answer to question 1, the n = 3 level consists of the sublevels 3*s*, 3*p*, and 3*d*. No 3*f* sublevel exists.

   The correct answer is (D).

   [LO 1.9 SP 6.4]

5. The abundance of the various isotopes is shown by the size of the peaks in the mass spectrum. According to the mass spectrum shown, X-22 is the most abundant , X-24 is next most abundant, and X-20 is least abundant.

   The correct answer is (B).

   [LO 1.14 SP 1.4, 1.5]

6. The average atomic mass can be obtained by multiplying the atomic mass of each isotope by its % abundance. An inspection of the mass spectrum shows that the average atomic mass cannot be less than 22.0, alternative (A), or equal to 22.0, choice (B), because of the greater abundance of X-24. Similarly, it cannot equal 23.0, selection (D), because isotopes X-22 and X-24 are not equally abundant and even if they were, the small abundance of X-20 would create a lower average. Inspection leads to answer (C). The calculation of the average atomic mass = $(0.10 \times 20) + (0.60 \times 22) + (0.30 \times 24) = 22.4$ amu provides confirmation.

   The correct answer is (C).

   [LO 1.14 SP 1.4, 1.5]

7. The difference in masses between the hydrate and the anhydrous salt after the last heating will equal the mass of water released. The moles of water present in the hydrate is obtained by dividing this value by 18, as in alternative (A). Option (B) incorrectly multiplies the mass of H_2O by the molar mass of H_2O. Selections (C) and (D) incorrectly use the mass of the solid after the first heating.

   The correct answer is (A).

   [LO 1.2 SP 2.2]

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8. The mass of the hydrate heated is less than recorded, as stated in options (A) and (B), but the mass of H_2O lost will be affected, so option (A) is not correct. While there is less H_2O in the hydrate that is heated, the loss of some of the hydrate means that the apparent loss of weight will be greater, not less, than the actual % as stated in option (B). The loss of hydrate after weighing, but before heating, means that the masses of the hydrate and the water lost cannot change proportionally, choice (C). The value of the hydrate mass used in the calculation is the recorded value. The mass of the residue left in the test tube, however, is lower, because less hydrate was used due to the spilling error. The result is a greater difference between the hydrate and the anhydrous salts masses, a seemingly greater mass of water lost, and, therefore, a greater % of water calculated.

   The correct answer is (D).

   [LO 1.2 SP 2.2]

9. The first heating removes a substantial % of the H_2O, 0.53 g out of 0.61 g. The further heating removes the remainder. Thus, after the first heating, a small amount of hydrate was still present along with the embedded water. After the first heating, the sample is NOT mostly hydrate, selection (A), nor does it have equal amounts of hydrate and anhydrous salt, option (B), because the mass of the sample is not halfway between the original sample and the anhydrous mass. It still contains some of the hydrated salt, which is removed with further heating, so choice (D) is not correct. Only after another heating did the remaining hydrate lose its water and become the anhydrous salt.

   The correct answer is (C).

   [LO 1.2 SP 2.2]

10. When HNO_3 is dissolved in H_2O, it ionizes completely to form H^+ and NO_3^- ions, which will conduct electricity well. N_2, option (B), is not very soluble in H_2O and forms no ions when it does. NH_2OH, choice (C), dissolves in H_2O but forms a solution with only a small number of ions, and NO, selection (D), is not very soluble and forms no ions.

    The correct answer is (A).

    [LO 2.1 SP 6.4]

11. The structure of HNO_3 involves two resonance forms with double bonds, so alternative (A) does not contain only sigma bonds. N_2, choice (B) has a triple bond, which consists of a sigma and two pi bonds. NH_2OH, option (C), contains only sigma bonds. NO, selection (D), has a double bond with a sigma and a pi bond.

    The correct answer is (C).

    [LO 2.1 SP 6.4]

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12. The energies of bonds increase with the number of bonds between the atoms. According to the description of the bonding in these four substance in question 11, the strongest bond in HNO_3, alternative (A), is the double bond in the two resonance forms. N_2, choice (B) contains a triple bond. NH_2OH, option (C), contains only single bonds and NO, selection (D), contains a double bond. The strongest of these is found in N_2, choice (B).

The correct answer is (B).

[LO 2.1 SP 6.4]

13. HNO_3, alternative (A), N_2, option (B), and NH_2OH, choice (C), all contain an even number of electrons and are unlikely to contain unpaired electrons. NO, selection (D), contains an odd number of electrons so it must have an unpaired electron.

The correct answer is (D).

[LO 2.1 SP 6.4]

14. An alkaline solution involves a base, such as options (C) or (D), not acids, such as choices (A) and (B). A soluble oxide that forms an alkaline solution is known as a basic anhydride, choice (C).

The correct answer is (C).

[LO 3.7 SP 6.1]

15. Non-metal oxides react with H_2O to form acidic solutions, so they are known as acid anhydrides, option (B). Some of these acid anhydrides may form solutions of strong acids, alternative (A), but they are not strong acids themselves.

The correct answer is (B).

[LO 3.7 SP 6.1]

16. A substance that undergoes 100% dissociation is considered a strong electrolyte. Of the choices given, the only one that specifies strong is (A), strong acid.

The correct answer is (A).

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17. Fe^{2+}, option (A), can be oxidized to Fe^{3+} or reduced to form Fe. In MnO_4^-, choice (B), Mn is in its highest oxidation state so can only be reduced. Cl^-, alternative (C), can be oxidized but cannot be reduced further. Al can be oxidized but cannot be reduced. The only species that can only be reduced is MnO_4^-.

    The correct answer is (B).

    [LO 3.8 SP 6.1]

18. As stated in question 17, Fe^{2+} can be oxidized to form Fe^{3+} or reduced to form Fe.

    The correct answer is (A).

    [LO 3.8 SP 6.1]

19. The half-life of a zero order reaction, alternative (A), is $[A_0]/2k$, which shows a dependence on concentration. The half-life of a first-order reaction, option (B), is $0.693/k$, while for a second order reaction, choice (C), it is $1/k[A_0]$ and that for a third-order reaction, selection (D), is $1/2k[A_0]^2$. The only one of these choices that does not include a dependence on concentration is the half-life expression for a first-order reaction.

    The correct answer is (B).

    [LO 4.3 SP 2.1]

20. The order of a reaction can be determined from the type of plot that produces a straight line. A zero-order gives a linear plot of concentration vs time, option (A). A first-order reaction, choice (B), is indicated by a linear plot of ln[ ] vs time. A second-order reaction, selection (C), gives a linear plot for 1/[ ] vs time.

    The correct answer is (A).

    [LO 4.2 SP 5.1]

21. The overall order of a reaction can be found by adding the exponents of the concentrations in the rate equation. In the rate equation given, each of the concentrations is raised to the first power, which gives a value of two for the sum. This reaction is second-order.

    The correct answer is (C).

    [LO 4.3 SP 5.1]

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22. The activation of the forward reaction is represented by the difference between the energy of the activated complex and the energy of the reactants. This energy is shown as A in the diagram.

    The correct answer is (A).

    [LO 4.6 SP 1.4]

23. When a catalyst is introduced to a reaction, it provides an alternate pathway with a lower activation energy, interval A on the diagram. If A is lowered, intervals C and D are also changed. The only interval that is not changed by the introduction of a catalyst is B, which corresponds to the energy difference between the reactants and products.

    The correct answer is (B).

    [LO 5.6 SP 2.2]

24. The activated complex occurs at the top of the peak on the energy profile. The potential energy of that peak is represented by the interval C.

    The correct answer is (C).

    [LO 5.6 SP 2.2]

25. Because the reaction as written is exothermic, increasing the temperature, option (A), will cause a shift toward the reactants. A decrease in pressure, choice (B), will cause a shift of the equilibrium toward the products, because two moles of $CO(g)$ would occupy twice the volume that one mole of $CO_2(g)$ would occupy. Removing $CO(g)$, alternative (D), would cause a shift toward the products. The only change that will cause no shift in the position of the equilibrium is the addition of a small amount of $C(s)$, selection (C), because the addition of a solid has no effect on the position of equilibrium, because solids do not appear in the equilibrium expression.

    The correct answer is (C).

    [LO 6.8 SP 1.4]

26. As stated in the answer to question 25, increasing the temperature will cause a shift toward the reactants because the reaction is exothermic and a shift toward reactants will decrease the quantity of heat in the system.

    The correct answer is (A).

    [LO 6.8 SP 1.4]

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27. When the temperature of a substance is increased, alternate (A), the average kinetic energy of the molecules increases and the kinetic energies of the molecules cover a greater range. Options (B), (C), and (D) have no effect on molecular kinetic energies.

    The correct answer is (A).

    [LO 5.2 SP 1.1]

28. Because the compounds all have similar structures (one cation and one anion), their relative solubilities can be determined by simply comparing the K_{sp} values. The most soluble substance is the one with the largest K_{sp}. The $K_{sp} = 2.4 \times 10^{-5}$ is larger than the other three values. $CaSO_4$ is the most soluble.

    The correct answer is (B).

    [LO 6.21 SP 2.2]

29. Because the compounds all have similar structures (one cation and one anion), their relative solubilities can be determined by simply comparing the K_{sp} values. The least soluble substance is the one with the smallest K_{sp}. The $K_{sp} = 1.8 \times 10^{-14}$ is smaller than the other three values, so $PbCrO_4$ is the least soluble.

    The correct answer is (C).

    [LO 6.21 SP 2.2]

30. The solubility of a compound is increased in acid solution if it reacts with H^+ ions. The SO_4^{2-} ion in $CaSO_4$, option (B), and the CrO_4^{2-} ion in $PbCrO_4$, choice (C), are anions of strong acids, so they will not react with H^+ ions. The CO_3^{2-} ion in $BaCO_3$, alternative (A), and the $C_2O_4^{2-}$ ion in ZnC_2O_4, selection (D), are anions of weak acids. These anions will react with H^+ to increase the solubility. $BaCO_3$ becomes much more soluble in acid, because the CO_3^{2-} reacts with H^+ ions to form H_2CO_3, which breaks down into CO_2 and H_2O.

    The correct answer is (A).

    [LO 6.23 SP 5.1]

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31. Alternatives (A) and (B) use the temperature in °C. Selection (D) converts the pressure into atmospheres and uses a ratio of volumes that is inverted. Temperature must be converted into Kelvin so that 30°C and 15°C become 303 and 288, respectively. The decrease in temperature will decrease the pressure by 288/303 but the decrease in volume from 2.5 L to 1.5 L will increase the pressure by 2.5/1.5.

The correct answer is (C).

[LO 2.6 SP 2.2, 2.3]

32. If the crucible contained H_2O with the magnesium, option (A), the Mg would seem to have a greater mass than its actual value. When compared with the mass of MgO formed, the seemingly greater amount of Mg would lead to a Mg % higher than the actual value. A warm crucible, alternative (B), would result in a lighter weight. This would lead to an apparent % Mg greater than the actual value. The presence of an oxide coating on the Mg, choice (C), yields an apparent larger mass of Mg, but would not form a greater mass of MgO so the percentage of Mg would be higher than the actual value. If the MgO absorbs H_2O before it is weighed, the apparent mass of the MgO would be greater so the % of Mg would seem to be *lower* than the actual value.

The correct answer is (D).

[LO 3.3 SP 2.2]

33. The relationship between the half-life of a first order reaction and its k value is $0.693 = kt_{1/2}$. For a half-life of 10.0 s, the k value would be 0.693/10.0 s or 0.0693 s^{-1}.

The correct answer is (A).

[LO 4.3 SP 2.1]

34. No reaction occurs between the gas and air, alternative (A). The gas is under pressure, so the release of some gas does not create a vacuum, choice (C). It is true that pressure and temperature of a gas are directly related, selection (D), but this does not explain this occurrence. Work is done as the gas from the can pushes the air molecules away, reducing the energy of the gas. The temperature drop of the gas is eventually transferred back to the can itself.

The correct answer is (B).

[LO 5.5 SP 2.2]

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35. For $HC_2H_3O_2$, the equilibrium expression is $K_a = [H^+][C_2H_3O_2^-]/[HC_2H_3O_2]$. For a solution in which $[HC_2H_3O_2] = [C_2H_3O_2^-] = 0.100\ M$, $[H^+] = 1.8 \times 10^{-5}$. The pH is obtained by taking the -log of the $[H^+]$. This will give a pH close to 5.00.

The correct answer is (C).

[LO 6.16 SP 2.2]

36. The increase in boiling temperature for these molecules is caused by greater surface area and more contact points for molecule to molecule dispersion forces, choice (A). Although an increase in mass correlates with the increase in boiling points, option (B), it does not explain the boiling points. Increasing the number of carbon atoms in the chain does not increase the polarity of the C-H bonds, selection (C), or the covalent bonding of the carbons within the molecule, alternative (D).

The correct answer is (A).

[LO 2.11 SP 6.2, 6.4]

37. The copper and the chloride ions are donors of electrons and would not react with each other. Sodium ions are very weak electron acceptors and would not react with the copper in a spontaneous reaction. No reaction would occur.

The correct answer is (A).

[LO 3.12 SP 2.2, 2.3, 6.4]

38. Catalysts do not alter the concentrations of reactants at equilibrium, alternative (A), or have any effect on the enthalpy change for the reaction, selection (C). Catalysts provide an alternate reaction pathway with a *lower* activation energy for both the forward and reverse reactions, rather than increasing the activation energy of the reverse process, choice (C). The lower activation energy increases the fraction of molecules with sufficient energy to react, option (B).

The correct answer is (B).

[LO 4.9 SP 6.2]

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39. Entropy provides a measure of the disorder in a system with an increase in entropy reflecting an increase in disorder. When $C_2H_5OH(l)$ is mixed with H_2O to form $C_2H_5OH(aq)$, choice (A), the system becomes more disordered with an increase in entropy. Similarly, the reaction of $C_2H_5OH(l)$ reacts with 3 $O_2(g)$ to form 2 $CO_2(g)$ and 3 $H_2O(g)$, selection (C), occurs with an increase in entropy because it involves an increase in the number of moles of gas. The decomposition of 2 $NH_3(g)$ to form $N_2(g)$ and 3 $H_2(g)$, alternative (D), also shows an increase in the number of moles of gas and, therefore, an increase in entropy. The only process for which there is a decrease in entropy is the dissolving of $CO_2(g)$ in H_2O, option (B), because aqueous carbon dioxide is more ordered than gaseous carbon dioxide.

The correct answer is (B).

[LO 5.12 SP 1.4]

40. Regardless of the temperature $K_w = [H^+][OH^-]$ and $[H^+] = [OH^-] = K_w^{1/2}$ for pure H_2O. When the value of K_w increases with an increase in temperature, $[H^+]$ will equal $[OH^-]$, and the solution will be neutral, not more or less acidic as in choices (A) and (C). The larger value for K_w will give a larger $[H^+]$ (and larger $[OH^-]$). Because $pH = -\log[H^+]$, the pH will decrease. As an example, for $K_w = 1 \times 10^{-12}$, $pH = -\log(1 \times 10^{-12})^{1/2} = 6$.

The correct answer is (B).

[LO 6.14 SP 2.2]

41. In diagram (A), the acid molecules are 100% dissociated so this diagram represents a strong acid. In diagram (B) one of eight HX molecules is dissociated as expected for a weak acid while in diagram (C) all of the acid molecules are undissociated and in diagram (D) half of the HX molecules are in the form of H^+ and X^- ions, representing a moderately strong acid. A weak acid will show a large number of acid molecules and a relatively smaller number of hydronium ions and conjugate anions.

The correct answer is (B).

[LO 2.9 SP 1.1, 1.4]

42. MnO_4^- ions, alternative (A), gain five electrons to form Mn^{2+} ions, so they undergo reduction in this reaction. H_2O_2, option (B), is converted to O_2 with a change in oxidation number from -1 to 0. Thus, H_2O_2 undergoes oxidation. H^+, choice (C), undergoes neither oxidation nor reduction with an oxidation number of +1 in H^+ and in H_2O. O_2, selection (D), is the result of the oxidation of H_2O_2.

The correct answer is (B).

[LO 3.8 SP 6.1]

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43. When the $[ClO_2]$ is doubled from 0.020 *M* to 0.040 at constant $[OH^-]$ in experiments one and two, the rate of the reaction increases by a factor of four so the order of ClO_2 is two. When the $[OH^-]$ is doubled from 0.030 to 0.060 at constant $[ClO_2]$ in experiments two and three, the rate doubles, so the order of $[OH^-]$ is one. The rate equation is Rate = $k[ClO_2]^2\,[OH^-]$.

The correct answer is (C).

[LO 4.2 SP 5.1]

44. The Heat of Combustion of methanol is calculated by subtracting the heat of formation of $CH_3OH(g)$ from the sum of the heat of formation of $CO_2(g)$ and two times the heat of formation of $H_2O(g)$ as shown in choice (B). Alternative (A) does not include the factor of two, while in option (C) the signs of all heats of formation have been changed and in selection (D) the heat of formation of CO_2 is subtracted and the heat of formation of CH_3OH is added rather than being subtracted.

The correct answer is (B).

[LO 5.8 SP 2.3, 7.1, 7.2]

45. The reaction given with a K_1 is reversed and divided by two for the new reaction. When a reaction is reversed the *K* expression is inverted. When a reaction is divided by two, the expression is raised to the one-half power. Applying these two rules, the K_1 of the original reaction would be inverted *and* raised to the one-half power to give $(1/K_1)^{1/2}$, choice (C). Option (A) shows K_1 divided by 2 while selection (B) has K_1 inverted but not raised to the one-half power and alternative (D) has K_1 raised to the one-half power but not inverted.

The correct answer is (C).

[LO 6.2 SP 2.2]

46. This question can be answered by converting each of the values to moles of P atoms. Thus, 11.2 L of gaseous P_2O_5 at STP, alternative (A), represents one half mole of P_2O_5 which would have one mole of P atoms. 500 mL of 6 *M* H_3PO_4, option (B), contain 3 moles of H_3PO_4 molecules and, therefore, 3 moles of P atoms. 124 g of P_4, choice (C), contains four moles of P atoms. Calcium phosphate, selection (D), has the formula $Ca_3(PO_4)_2$ so 2.5 moles would contain 5 moles of P atoms. Of these values, the largest is the last.

The correct answer is (D).

[LO 1.4 SP 7.1]

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47. Silicon dioxide, option (A), consists of a network of covalently bonded silicon and oxygen atoms so melting it would require breaking covalent bonds. Ice, alternative (B), contains individual H_2O molecules bonded to one another by hydrogen bonds that would have to be broken to melt ice. Wax, choice (C), is a non-polar molecule that would be held to others in the solid by dispersion forces. NaCl, selection (D), is an ionic compound. Melting it would require breaking ionic bonds. The only one of these that would involve breaking covalent bonds is SiO_2.

The correct answer is (A).

[LO 2.30 SP 1.1, 6.2, 7.1]

48. A Bronsted-Lowry (B-L) acid is defined as a proton donor and a B-L base is a proton acceptor. The F^- ion, option (A), has no protons to donate so cannot function as a B-L acid. The HSO_4^- ion, choice (B), can donate a proton to form the SO_4^{2-} ion and accept a proton to form H_2SO_4. The H_3O^+ ion, selection (C), can behave like a B-L acid by donating a proton but cannot gain an additional H^+ to act as a B-L base. The CO_3^{2-} ion, alternative (D), can gain a proton to form HCO_3^- (acting as a B-L base) but has no protons to donate.

The correct answer is (B).

[LO 3.7 SP 6.1]

49. In order to obtain the overall equation for a reaction from the two equations of the mechanism, the two equations should be added, eliminating any intermediates that are formed in the first step and consumed in the second step. The equation in alternative (A) contains the intermediate $NO_3(g)$. The option (B) equation has an extra $NO_2(g)$ on each side. Choice (C) is the correct equation. Selection (D) is simply the equation for the second step of the mechanism.

The correct answer is (C).

[LO4.7 SP 6.5]

50. Because the three cylinders have the same mass and temperature, their relative temperatures after heating will depend on their specific heat capacities. The three cylinders will not have the same temperature as stated in alternative (A). Cu has the lowest specific heat and would show the greatest ΔT given the same heat input and the same mass as the other metal cylinders. The Al cylinder (with the highest specific heat) would exhibit the smallest ΔT and the Fe cylinder would be in the middle.

The correct answer is (B).

[LO 5.3 SP 7.1]

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51. The loss of a positron from the nucleus would remove a positive charge, but does not change the mass. This is equivalent to converting a proton to a neutron, thus increasing the neutron:proton ratio, alternative (A). It would not affect the mass number, option (B), increase the atomic number, selection (C), or increase the number of electrons, choice (D).

    The correct answer is (A).

    [LO 1.18 SP 1.4]

52. This exothermic reaction involves a decrease in volume from the reactants to products. Because heat is released during the reaction, the equilibrium yield of $COCl_2(g)$ will be increased by lowering the temperature, which will remove some of the released heat. Because the product occupies a smaller volume than the reactants, an increase in pressure will promote the formation of more $COCl_2(g)$. Alternative (A) has the pressure correct but the temperature incorrect. Both factors in selection (B) are incorrect. Choice (C) has the temperature correct but the pressure incorrect.

    The correct answer is (D).

    [LO 6.9 SP 4.2]

53. Container type, surface area, and volume of liquid have no effect on the vapor pressure. The lowest vapor pressure will be observed for the strongest intermolecular forces and the lowest temperature. The intermolecular forces in ethyl alcohol are stronger (due to hydrogen bonding) than those in diethyl ether (dispersion forces). Choices (B) and (D) will have lower vapor pressures than alternatives (A) and (C). Because the temperature in choice (D) is lower than that in choice (C), (D) will have the lowest vapor pressure.

    The correct answer is (D).

    [LO 2.16 SP 6.2]

54. When C is oxidized to CO_2, its oxidation state (ox. st.) changes from 0 to +4. This oxidation would require 4 HNO_3 (ox. st. of N = + 5) and 4 NO_2 (ox. st. = + 4) with two H_2Os being formed. Four moles of electrons would be transferred.

    The correct answer is (C).

    [LO 3.8 SP 6.1]

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55. The rate-determining step for a reaction need not be the first step, depending on the mechanism, so alternative (A) is incorrect. It will be the slowest step, option (B), which will have the highest activation energy, not the lowest as stated in selection (D). The number of collisions, choice (C), has little to do with the determination of the rate-determining step.

The correct answer is (B).

[LO 4.7 SP 6.5]

56. Doubling the temperature will not double the area under the Maxwell-Boltzman distribution because the total number of molecules will remain the same, so alternative (A) is incorrect. The curve will spread toward higher molecular speeds, option (B). It will become flatter so the maximum will not become higher as stated in choice (C). The average kinetic energy of the molecules will be doubled but the maximum molecular speed will not double, as in selection (D).

The correct answer is (B).

[LO 5.2 SP 1.1]

57. Alternative (A), 1.0 M HOCl and 1.0 M NaOCl, will have a high buffer capacity but will have a pH near 8. Option (B), with 0.5 M $HC_3H_5O_3$ and 0.50 M $NaC_3H_5O_3$, will have a $pH = -\log(1.4 \times 10^{-4})$, which will be close to 4.0. Choice (C), has a higher concentration of $HC_3H_5O_3$ but a lower concentration of $NaC_3H_5O_3$, resulting in a lower capacity than choice (B). Solution (D) will have a pH near 8.

The correct answer is (B).

[LO 6.18 SP 2.3]

58. CO, alternative (A), has a triple bond that will have the shortest, not the longest bond length. CO_2, option (B), has two double bonds, making the average bond length slightly longer than that in CO. CH_3CO_2 , choice (C), consists of two resonance forms containing one double bond and one single bond to give an average bond order of 1.5. CO_3^{2-}, selection (D), has three resonance forms, each of which has one double bond and two single bonds for an average bond order of 1.3. The bond length between two atoms increases as the bond order decreases.

The correct answer is (D).

[LO 2.21 SP 1.4]

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59. In a saturated solution, adding more water, alternative (A), will not increase the solubility, it will just cause more of the solid to dissolve to keep the solution saturated. Adding a solution containing Ca^{2+} and CO_3^{2-} ions, option (B), will not increase the solubility which is determined by the equilibrium for $CaCO_3$ [$CaCO_3$ (s) $\rightleftharpoons$ Ca^{2+} (aq) + CO_3^{2-} (aq)]. Adding a solution of H_3O^+ ions will shift the equilibrium to the right as the carbonate ion reacts with the H_3O^+ and increase the solubility of the calcium carbonate. Adding a solution of OH^- ions will have no effect on the solubility of $CaCO_3$(s).

The correct answer is (C).

[LO 6.23 SP 5.1]

60. A negative value of ΔH°, alternative (A), will promote a spontaneous reaction but will not guarantee it. A positive ΔG°, option (B), indicates a non-spontaneous reaction, not a spontaneous one. A negative ΔS°, choice (C), does not favor a spontaneous reaction under any conditions. A positive value of E° always indicates a spontaneous reaction according to the equation $\Delta G^\circ = -nFE^\circ$

The correct answer is (D).

[LO 5.13 SP 2.1]

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CONSTRUCTED-RESPONSE SOLUTIONS

Question 1 Big Idea 3

The solid $K_2C_2O_4$ is weighed, dissolved in 25 mL of water, and 5 mL of H_2SO_4 is added to acidify the solution in the flask. The solution is then titrated in 3 trials with the $KMnO_4$ from the buret until a persistent pale color remains. The data table for the 3 different trials is below.

Trial	Mass of solid $K_2C_2O_4$	Volume of $KMnO_4$ solution
1	0.250 g	31.15 mL
2	0.250 g	31.05 mL
3	0.250 g	31.05 mL

(a) The oxidation number of carbon in $C_2O_4^{2-}$ is +3 and changes to an oxidation number of +4 in CO_2. Therefore the $C_2O_4^{2-}$ ions are losing electrons; this process is *oxidation*.

[LO 3.8 SP 6.1]

(b) $0.250\text{ g } K_2C_2O_4 \times \frac{1\text{ mol } K_2C_2O_4}{166\ K_2C_2O_4} = 1.51 \times 10^{-3}\text{ mol } K_2C_2O_4$

[LO 3.4 SP 2.2, 5.1, 6.4]

(c) $1.51 \times 10^{-3}\text{ mol } K_2C_2O_4 \times \frac{2MnO_4^-}{5\ C_2O_4^{2-}} = 6.024 \times 10^{-4}\text{ moles } MnO_4^-$

The # of moles of $KMnO_4$ = moles of MnO_4^- = 6.024×10^{-4} mol
The molar concentration of $KMnO_4$ = 6.024×10^{-4} moles/0.03105 L = 0.0194 *M*

[LO 1.19 SP 4.2, 5.1]

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(d) i. Rinsing the buret with H_2O but not with the $KMnO_4$ solution, would dilute the $KMnO_4$ solution, requiring a larger volume to be added to react with all of the solid.

ii. If a small amount of solid remained in the weighing boat, there would be fewer moles of $K_2C_2O_4$ in the flask. Fewer moles of $K_2C_2O_4$ present in the flask would require a smaller volume to reach the endpoint of the reaction.

[LO 1.20 SP 4.2, 5.1]

PART II

(e) The moles of $KMnO_4$ can be determined by $M \times V$.

$$0.0347\text{L} \times 0.0214\ \text{mol/L} = 7.426 \times 10^{-4}\text{mol}\ MnO_4^- \times \frac{5\ \text{mol}\ H_2O_2}{2\ \text{mol}\ MnO_4^-} \times \frac{34.02\text{g}\ H_2O_2}{1\ \text{mol}\ H_2O_2} = 0.0633\text{g}$$

With the assumption of the density of the solution = 1.00g/mL,

$$\%\ H_2O_2 = \frac{0.0633\ \text{g}\ H_2O_2}{3.00\ \text{g solution}} \times 100\% = 2.11\%\ H_2O_2$$

(f) A larger volume of $KMnO_4$ would result in a larger number of moles of MnO_4^- and a larger number of moles of H_2O_2. This would result in a larger mass of H_2O_2 and lead to a **larger calculated value for the percent H_2O_2.**

(g) i. Analyte: the substance in an analysis whose concentration (e.g., molarity or %) value is unknown.
Titrant: a solution of known concentration used to determine the amount of moles of analyte reacted in a titration.

ii. In this lab, there was a substance that served as both a titrant and an analyte. Identify the substance and explain how it acted as both. The $KMnO_4$ solution is the analyte in Part I because the goal was to determine its molarity. In Part II, its molarity was known and its volume delivered from the buret was used to calculate the moles of H_2O_2.

[LO 1.19 SP 4.2, 5.1] [LO 1.20 SP 4.2, 5.1]

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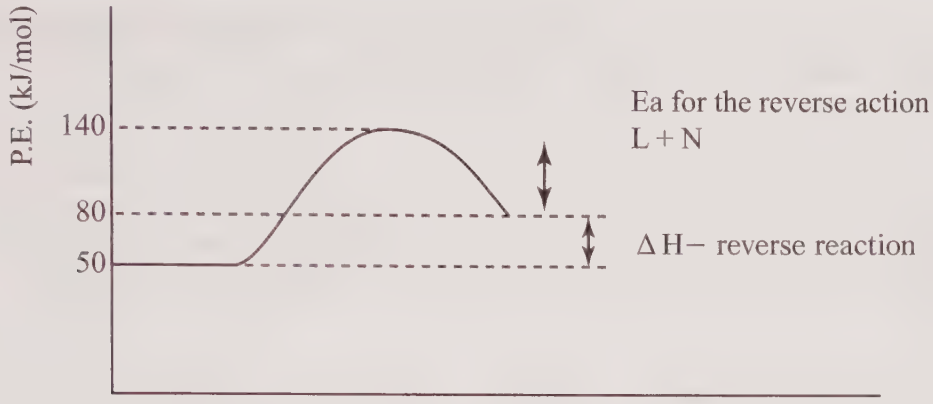
Question 2

(a)



(b) The roles of the products and reactants are reversed;
ΔH = products − reactants = 50 − 80 = −30 kJ/mol

(c) If the reactants contain 50 kJ of potential energy and absorb 90 more kJ/mole (the activation energy of the forward reaction), then the total energy in the activated complex (transition state intermediate) is 140 kJ/mol

(d) In the reverse reaction, the L + N substances start out with 80 kJ/mol and must absorb sufficient energy to reach the activated complex (140 kJ/mole). For 80 → 140, the L + N products must absorb 60 kJ/mol.

(e) The slowest step in the "reaction mechanism" here (like the weakest link in a chain) determines the overall flow rate. Funnel A has the slowest flow rate (2 mL/sec) so the overall output rate in Set-up I cannot exceed 2 mL/sec without overflowing. Therefore, the overall output rate in System I is 2 mL/sec.

(f) Again, the slowest step in the "reaction mechanism" (like the weakest link in a chain) determines the overall flow rate. Funnel A has the slowest flow rate (2 mL/sec) and no matter where the funnel appears in the "reaction mechanism," the overall output rate is defined by funnel A. Therefore, the overall output rate in System II is also 2 mL/sec.

[LO 4.1 SP 4.2, 5.1]

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Question 3

(a) Substance C is responsible for the color. Whenever C is present, the solutions are colored, but when substance C is absent, the solutions are colorless.

[LO 3.10 SP 1.4, 6.1)

(b) Trial 2 provides the strongest evidence, because when substance A is absent, no warmth is detected, (and whenever substance A is present, the solution becomes noticeably warmer).

[LO 3.11 SP 4.1]

(c) Her hypothesis is false, because the solution is capable of 3 colors here when C is present: yellow, red and magenta. If the color were caused by food coloring, the solutions would remain the same red color, maybe darker or lighter, but different colors can appear when an acid-base indicator is present and the solution pH changes.

(d) Substance B is present whenever bubbles are detected, and no bubbles appear when B is absent. *B is definitely required* in order for bubbles to form. In trial 4, when substance C is absent, some bubbles still form, so C is not needed; in trial 2, when A is present, some bubbles are detected, so A is not necessary for the bubbles. That leaves substance B and water must be the ingredients that cause bubbles to form. Perhaps Substance A provides the needed heat or activation energy to cause a more vigorous bubbling reaction.

[LO 1.13 SP 5.3]

(e) $XY(s) + \text{heat} \rightarrow X^{+}(aq) + Y^{-}(aq)$ or any variation where the charges on the X and Y ions have the same magnitude.(e.g 2+ and 2−). The equation could also be written as $XY_{(s)} + q \rightarrow X^{+}_{(aq)} + Y^{-}_{(aq)}$, where "q" is commonly used in thermal equation to indicate heat. The heat term MUST, however, appear on the reactant side, as the solution becoming colder [XY + C + water] clearly indicates an endothermic reaction.

(f) The second diagram is the one to be circled. When the solution becomes colder, the system (reactant) has *absorbed energy* from the surroundings, causing the kinetic energy (temperature) of the surroundings to drop.

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Question 4

(a) The greater the charge on the positive ions, the greater the attraction of the ions to the negatively charged plate in the diagram. Beam (B) comes down to the plate first. Therefore Beam (B) represents the higher charged, X^{2+} ions (and beam (A) represents the X^{+} ions).

(b) All of the ions in a beam have the same charge, so slight differences in location represent slight differences in mass, of isotopes. The heavier the isotope, the more momentum it will have (momentum = Mass x V) and the farther it will travel before coming to rest. Therefore, beams 3 and 6 represent the heaviest isotopes; beam 3 = $^{32}X^{2+}$ and beam 6 = $^{32}X^{+}$.

[LO 1.14 SP 1.4, 1.5]

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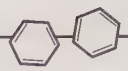

Question 5

(a) The equilibrium moles of CO_2 = ¼ the moles H_2 = ¼ × 0.800 mol = 0.200 mol CO_2. The number of moles of H_2O *reacted* at equilibrium = ½ the equilibrium moles of H_2, formed = ½ 0.800 = 0.400 mol H_2O. With one mole H_20 initially, the equilibrium mixture will contain 1.00 – 0.400 = 0.600 mol H_2O. Using a similar approach for the equilibrium concentration of CH_4, 1.00 mol – 0.200 mol reacted = 0.800 mol CH_4 remaining at equilibrium. With a 1.00L flask, the moles of each substance = the molarity. The K_c expression here

$$= \frac{[H_2]^4\,[CO_2]}{[H_2O]^2\,[CH_4]} = \frac{(0.800)^4\,[0.200)}{(0.600)^2\,(0.800)} = 2.84 \times 10^{-1} = K_c$$

[LO 6.5 SP 2.2]

(b) The equilibrium will initially shift in a larger container but when equilibrium is re-established , the value for K_c will be the same **at the same temperature (800K)**.

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Question 6

(a)

(b) $CHCl_3$ and SF_4 are polar.

(c) Heavier mass does NOT account for the differences. Even though CCl_4 is non polar and $CHCl_3$ is polar, the number of valence or outer electrons on CCl_4 is larger, and the molecule has a larger surface area. These two factors lead to the presence of more instantaneous attractions *between molecules*, stemming from the larger number of "polarizeable electrons." Another contributing factor is the symmetrical shape of the CCl_4 molecule, allowing for the molecules to pack in closer to one another, again contributing to stronger surface attractions between molecules.

[LO 2.4 SP 1.4, 6.4]

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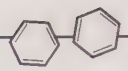

Question 7

(a) The mass of the empty calorimeter and the mass of copper sulfate solution + calorimeter, and the initial and final temperatures, so that ΔT can be determined. ΔT alone is insufficient- it can be calculated but not directly measured.

[LO 5.7 SP 4.2, 5.1]

(b) $\Delta G = -nF\ E_{cell}$. If the voltage (E_{cell}) is positive, the sign of ΔG is negative.
Alternative answer:
A negative ΔG is associated with spontaneous reactions, reactions that do occur at a given temperature. A positive voltage indicates the reaction is spontaneous, that it is occurring, so the sign of ΔG must be negative.

[LO 5.4 SP 2.2]

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SAMPLE EXAMINATION 3

1. Ionization energy, alternative (A), is defined as the energy required to remove an electron from a gaseous atom. Electron affinity, option (B), is defined as the energy change that accompanies the gain of an electron. Electronegativity, choice (C), is the relative ability of an atom to attract electrons in a chemical bond. Electropositivity, selection (D), provides a qualitative measure of the tendency of an atom to lose an electron.

   The correct answer is (B).

   [LO 1.5 SP 1.5]

2. The energy required to remove an electron from an atom to an infinite distance is the ionization energy. The definitions for the other choices are given in the answer to question 1.

   The correct answer is (A).

   [LO 1.5 SP 1.5]

3. The attraction for electrons in a chemical bond is defined as the electronegativity. The definitions for the other choices are given in the answer to question 1.

   The correct answer is (C).

   [LO 1.5 SP 1.5]

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4. Chlorine with the formula Cl_2, choice (A), is diatomic as are nitrogen, N_2, option (C), and oxygen, O_2, selection (D). The only one of the gases that is monatomic is the noble gas, He, selection (B).

   The correct answer is (B).

   [LO 1.9 SP 6.4]

5. The requirement for a paramagnetic substance is the presence of one or more unpaired electrons. Chlorine, option (A), has all of its electrons paired and is not paramagnetic. Helium, alternative (B), possesses two paired electrons. It is not paramagnetic. Nitrogen, choice (C), contains ten valence electrons in a triple bond between the two atoms with lone pairs on each atom. There are no unpaired electrons. Oxygen, selection (D), has 12 valence electrons that could all be paired in a Lewis structure. This alludes to The Molecular Orbital Theory. However, a better representation using the Molecular Orbital Theory assigns two of these electrons to separate orbitals, making it paramagnetic. This paramagnetic nature is exhibited when liquid oxygen is held between the poles of a very strong magnet.

   The correct answer is (D).

   [LO 2.1 SP 6.4]

6. Chlorine, alternative (A), has two atoms bonded to one another by a single (sigma) bond. Helium, option (B), forms no bonds. A nitrogen molecule, N_2, consists of two nitrogen atoms bonded to one another by a triple bond. This bond consists of a sigma and two pi bonds. Oxygen, O_2, selection (D), has a double bond, which can be represented as having a sigma and a pi bond.

   The correct answer is (C).

   [LO 2.1 SP 6.4]

7. Chlorine, alternative (A), is a pale green gas. Helium, option (B), nitrogen, choice (C), and oxygen, selection (D), are all colorless.

   The correct answer is (A).

   [LO 2.1 SP 6.4]

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8. Isotopes are two or more elemental species that have a specified number of protons but a variable number of neutrons. Sodium carbonate and ammonium nitrate, alternative (A), are ionic compounds. Carbon-12 and carbon-14, option (B), are isotopes, each of which has six protons but one has six neutrons and the other has eight. Diethyl ether and 2-hydroxybutane, choice (C), are examples of isomers with the same molecular formula but different structures. Diamond and Graphite, selection (D), are different forms of an element, known as allotropes. Therefore, C-12 and C-14 represent a pair of isotopes.

   The correct answer is (B).

   [LO 1.14 SP 1.4]

9. Sodium carbonate and ammonium nitrate, selection (A), are ionic compounds. The carbonate anion, the ammonium cation, and the nitrate anion all contain covalent bonds so this pair contains both covalent and ionic bonds. C-12 and C-14, option (B), are atoms and contain no bonds, covalent or ionic. Diethyl ether, and 2-hydroxybutane, choice (C), contain only covalent bonds. Diamond and graphite, alternative (D), contain covalent bonds only.

   The correct answer is (A).

   [LO 2.1 SP 6.4]

10. Allotropes are forms of a given element in which the atoms have different arrangements. As stated above, choice (A) is a pair of ionic compounds. Option (B) is a pair of isotopes. Choice (C) is a pair of isomers. Diamond and graphite both consist of carbon atoms with the atoms in diamond arranged in a tetrahedral structure containing single bonds while those in graphite are arranged in six-member rings with delocalized bonds.

    The correct answer is (D).

    [LO 2.1 SP 6.4]

11. Isomers have the same molecular formulae but different structures, as exemplified by diethyl ether and 2-hydroxybutane.

    The correct answer is (C).

    [LO 2.1 SP 6.4]

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12. A barometer, option (A), is used to measure atmospheric pressure. A pH meter and probe, choice (B), can be used to measure the pH of a solution and, thus, create a titration curve. A separatory funnel, alternative (C), is used to separate two immiscible liquids with different densities. A spectrophotometer, selection (D), is used to measure the absorbance of a colored solution.

    The correct answer is (B).

    [LO 3.4 SP 2.2]

13. Beer's Law, A = abc, is a statement of the relationship between the absorbance of a solution, A, and the molar absorptivity, a (a constant that is characteristic of the absorbing substance), b, the thickness of the solution, and c, the concentration of the absorbing substance. Measurements of absorbance as a function of concentration could be used to verify this law, for which a spectrophotometer could be used.

    The correct answer is (D).

    [LO 1.16 SP 2.2]

14. As stated in the answer to question 12, immiscible liquids of different densities can be separated by means of a separatory funnel.

The correct answer is (C).

[LO 3.4 SP 2.2]

15. The molar mass of a volatile liquid can be found by capturing a weighed sample of the vapor in a container of known volume at a known temperature and pressure. The molar mass is calculated from the mass of the sample, the P and T by means of the ideal gas equation; PV = (g/MM)RT. The pressure can be measured with a barometer.

    The correct answer is (A).

    [LO 3.4 SP 2.2]

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16. The information in the table states that metal I is a reddish solid that does not react with HCl(*aq*), but does react with $HNO_3(aq)$ to produce reddish-brown bubbles. Silver, Ag, option (A), is silvery in appearance not reddish so, although it reacts with $HNO_3(aq)$, cannot be metal I. Gold, alternative (B), appears yellow but only reacts with a mixture of HCl(*aq*) and $HNO_3(aq)$ rather than either one separately, so cannot be metal I. Copper, choice (C), is reddish in appearance, does not react with HCl(*aq*) but does react with $HNO_3(aq)$ with the results described. Zinc, selection (D), has a silvery appearance and reacts with both HCl(*aq*) and $HNO_3(aq)$, so cannot be metal I.

The correct answer is (C).

[LO 3.8 SP 6.1]

17. The atomic masses of the four solids are; Ag–108, Au–197, Cu–63, and Zn–65, respectively. The only one of these metals that could consist of isotopes 107 and 109 is Ag.

The correct answer is (A).

[LO 1.14 SP 1.4]

18. The interval AB, (the difference between the energy of the reactants and the energy of the activated complex), alternative (A), represents the activation energy for the forward reaction. The interval CD, option (B), is the difference in the energies of the products and reactants. Interval DE, choice (C), represents the activation energy for the reverse reaction. Point F, selection (D), is the energy of the activated complex. ΔH is calculated from Products − Reactants, so the answer is (B).

The correct answer is (B).

[LO 5.7 SP 4.2]

19. The E_a for the reverse reaction is the minimum energy absorbed by the products to form the activated complex.

The correct answer is (C).

[LO 4.6 SP 6.4]

20. The energy associated with point F represents the energy stored in the activated complex relative to either the reactants or products.

The correct answer is (D).

[LO 4.6 SP 6.4]

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21. The rate of this (and most other) reactions will be increased by raising the temperature, alternative (A). The pressure of $H_2(g)$, selection (B), is a reaction product and is unlikely to have any effect on the rate of the forward reaction. The size of the zinc particles, choice (C), will affect the rate of the reaction. For a given mass of Zn, as the size of the particles, choice (C), is decreased the surface area is increased and the rate will increase. The concentration of $H^+(aq)$, option (D), will affect the rate of the reaction, increasing the rate as the concentration is increased. The reaction rate will increase with a decrease in the size of the Zn particles.

    The correct answer is (C).

    [LO 4.1 SP 4.2]

22. As stated in the answer to question 21, increasing the temperature, alternative (A), will increase the rate of the reaction. It will also increase the volume of $H_2(g)$ as indicated by the ideal gas equation, PV = nRT. An increase in the pressure of $H_2(g)$, option (B), will not affect the reaction rate. An increase in the size of the Zn particles, choice (C), will decrease the rate of the reaction. An increase in the concentration of $H^+(aq)$, selection (D), will increase the reaction rate, but if the number of moles of $H^+(aq)$ is constant, the volume of $H_2(g)$ will be also.

    The correct answer is (A).

    [LO 4.1 SP 4.2]

23. As stated in the answer to question 21, the reaction rate will not be affected by the pressure of $H_2(g)$.

    The correct answer is (B).

    [LO 4.1 SP 4.2]

24. An increase in pressure will shift a reaction toward the side with the smaller volume of gas. The reaction of $S(s) + O_2(g)$ to give $SO_2(g)$, choice (A), has the same number of moles of gas on both sides of the equation, as does the reaction of $H_2(g)$ and $I_2(g)$ to form 2 $HI(g)$, option (B). The decomposition of $PCl_5(g)$ to give $PCl_3(g)$ and $Cl_2(g)$, alternative (C), will be shifted toward the reactants with an increase in pressure. The reaction of 2 $NO(g)$ with $O_2(g)$ to form 2 $NO_2(g)$, selection (D), is the only reaction for which the products have a smaller volume than the reactants.

    The correct answer is (D).

    [LO 6.8 SP 1.4]

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25. The reaction $S(s) + O_2(g) \rightleftharpoons SO_2(g)$, alternative (A), in which a solid and a gas are converted to a more complex gas, will exhibit a slight increase in ΔS. The reaction, $H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$, option (B), involves the presence of two moles of gas in both the reactants and products will have a very small ΔS at most. In the reaction, $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, choice (C), one mole of gas is converted into two. It will exhibit a large increase in ΔS. The reaction of 2 $NO(g)$ with $O_2(g)$ to give 2 $NO_2(g)$, selection (D), will occur with a decrease in entropy.

The correct answer is (C).

[LO 5.12 SP 1.4]

26. A negative ΔG° will result from a large negative ΔH° and a positive (or very small) ΔS° or a very small ΔH° and a large positive ΔS°. The reaction in alternative (A) has a large negative ΔH° and a small positive ΔS° that will give a negative ΔG°. The reaction in option (B) has a positive value for ΔH° and a very small ΔS° that will yield a positive value for ΔG°. The reaction in choice (C), with a positive value of ΔH° and a negative value for ΔS°, will give a positive ΔG°. The reaction in selection (D), with a negative ΔH° and a negative ΔS°, will have a negative ΔG°. The ΔG° value for the reaction in alternative (A) will be more negative than that for selection (D).

The correct answer is (A).

[LO 5.13 SP 2.2]

27. In order to increase the $[Mg^{2+}]$, the equilibrium will have to be shifted toward the products. Adding NaF, alternative (A), would shift the equilibrium toward $MgF_2(s)$, because F^- is one of the products of the dissociation of $MgF_2(s)$. Adding HCl(aq), option (B), will shift the equilibrium toward the products, because the H^- ions from $HCl(aq)$ will react with $F^-(aq)$ ions to form the weak acid HF. Evaporating the solution to one-half its original volume, choice (C), will not affect the $[Mg^{2+}]$, but will increase the amount of solid. Increasing the temperature, selection (D), will increase the solubility slightly, because it will change the value of K_{sp}. The greatest increase in $[Mg^{2+}]$ will be caused by adding $HCl(aq)$.

The correct answer is (B).

[LO 6.23 SP 5.1]

28. As stated in the answer to question 27, evaporating a saturated solution to one-half of its original volume has no effect on the concentrations of the ions in solution.

The correct answer is (C).

[LO 6.23 SP 5.1]

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29. Although adding substances to a system at equilibrium, as in options (A) and (B), may alter the position of the equilibrium, they do not affect the value of the K_{sp}. The value of K_{sp} is not affected by evaporating the solution, choice (C). The only factor that can affect the value of an equilibrium constant is the temperature.

    The correct answer is (D).

    [LO 6.23 SP 5.1]

30. The energies of the lines in a PES diagram reflect the energies with which the electrons are attracted to the nucleus. The intensity of the lines provide a measure of the number of electrons with the respective energies. The diagram shows two electrons with an energy above 100, two with an energy of about 7, six electrons with an energy near 3 and one electron with an energy about 1. This electron configuration, $1s^2\ 2s^2\ 2p^6\ 3s^1$, corresponds to Na.

    The correct answer is (C).

    [LO 1.6 SP 5.1]

31. Ideal gas behavior is more likely to be exhibited by small gas molecules that occupy little space and are less subject to intermolecular forces. Of the two molecules listed, He is the smaller with only dispersion forces compared to NH_3 that is polar with hydrogen bonding, making helium behave more ideally. In addition, low pressure and high temperature also promote more ideal behavior because the molecules are farther apart and move faster. Choice (B) has all three factors.

    The correct answer is (B).

    [LO 2.4 SP 1.4, 6.4]

32. A strong acid will show complete dissociation of the acid into hydronium ions and conjugate anions. No HX molecules will be present. In alternative (A), no HX molecules are present, while in option (B), most of the species are undissociated. In choice (C), all of the HX species are in molecular form, and in selection (D), approximately 50% of the molecules are dissociated.

    The correct answer is (A).

    [LO 2.9 SP 1.1, 1.4]

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33. In SiO_2, alternative (A), the Si and O atoms are bonded to one another by covalent bonds that would have to be broken when it is melted. In solid H_2O, selection (B), the molecules are bonded to one another by hydrogen bonds, as well as bydispersion forces. Wax, choice (C), is a non-polar molecule that exhibits only dispersion forces between its molecules. NaCl, option (D), is held together by means of ionic bonds.

The correct answer is (C).

[LO 2.16, 2.32 SP 1.1, 6.2, 7.1]

34. The melting points of ionic solids can be evaluated by means of Coulomb's Law; $F = q_1q_2/D^2$, where q_1 and q_2 are the charges on the ions and D represents the internuclear distance. Melting points will increase as the charges on the ions increase and the distance between them decreases. NaF, option (A), consists of +1 and −1 ions. NaBr, alternative (B), would have a lower melting point than NaF due to the larger distance between the +1 and −1 ions. In $MgCl_2$, choice (C), the Mg^{2+} ion would double the attractive force. In MgO, selection (D), the attractive force would be at least four times as great due to the charges on both the Mg^{2+} and the O^{2-} ions and the shorter distance between them due to the smaller size of both the Mg^{2+} and O^{2-} ions, compared to the sizes of the Na^+ and CI^- ions.

The correct answer is (D).

[LO 2.19 SP 1.4]

35. Bond lengths are inversely related to bond strengths. CO, alternative (A), has a triple bond between the C and the O. In CO_2, option (B), each of the O atoms is bonded to the C via a double bond. In the $CH_3CO_2^-$ ion, choice (C), the two O atoms are bonded to the C atom in a resonance structure with each C–O bond having an average bond strength of 1 1/2. The CO_3^{2-} ion, selection (D), is best represented as a resonance hybrid with an average bond strength of 1 1/3. When these bonds are arranged in order of increasing strength (and decreasing bond length) the order is CO_3^{2-}, $CH_3CO_2^-$, CO_2, CO. The shortest C–O bond length is found in CO.

The correct answer is (A).

(LO 2.21 SP 1.4]

36. When Mg reacts with O_2, the compound MgO is formed. From the atomic masses of Mg = 24 and O = 16, the molar mass of MgO = 40. The ratio of the mass of MgO/Mg is 40/24 or 1.67/1. Alternative (A), 0.67/1, is the ratio for the masses of O/Mg. Option (B), 1.67/1, has the correct ratio. Choice (C), 2.33/1, is the ratio that would occur if the formula for magnesium were MgO_2. Selection (D), 2.5/1, is the ratio for the mass of MgO/O.

The correct answer is (B).

[LO 3.3 SP 2.2]

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37. The test tube becomes cold to the touch, so heat is being absorbed from the surroundings, which makes the dissolving process endothermic, options (A) or (B). An endothermic process has $\Delta H > 0$.

The correct answer is (B).

[LO 3.11 SP 1.5]

38. 40 mL of 0.01 M $KMnO_4$ solution contains 0.0004 moles of MnO_4^- ions (0.04 L X 0.01 mol/L). According to the balanced equation the ratio of H_2O_2/MnO_4^- is 5/2 so the number of moles of H_2O_2 is $5/2\,(0.0004) = 0.001$ moles. Alternative (A), 0.0002 mol, is the result of multiplying the moles of MnO_4^- by 2/5 rather than 5/2. Option (B), 0.0004 mol, is the number of moles of MnO_4^-. Choice (C), 0.001 mol, is the correct answer. Selection (D), 1.0 mol, is the result obtained by not converting 40 mL to L.

The correct answer is (C).

[LO 3.4 SP 2.2, 5.1, 6.4]

39. The voltage for a redox reaction can be obtained by adding the SRP for a reduction process to the negative SRP of an oxidation process. For the reaction of $Mg(s) + Pb^{2+}(aq)$, alternative (A), the potential would be $2.36\text{ V} - 0.12\text{ V} = 2.24\text{ V}$. The voltage for the reaction of $Cl_2(aq) + 2\,I^-(aq)$, option (B), would be $1.36\text{ V} - 0.54\text{ V} = 0.82\text{ V}$. The voltage for $Mg(s) + 2\,Ag^+(aq)$, choice (C), would be $2.36\text{ V} + 0.80\text{ V} = 3.16\text{ V}$. The voltage for $Mg^{2+}(aq) + 2\,Cl^-(aq)$, selection (D), would be $-2.36\text{ V} - 1.36\text{ V} = -3.72\text{ V}$.

The correct answer is (C).

[LO 3.12 SP 2.2]

40. When this voltaic cell operates, the Zn(s) undergoes oxidation to form Zn^{2+} ions. The electrons released during the oxidation of Zn are transferred to the $Cu^{2+}|Cu$ half cell where the Cu^{2+} ions undergo reduction. Thus, oxidation does not happen at the copper electrode, so alternative (A) is not correct. Electrons move from the Zn electrode to the Cu electrode so option (B) is not correct. The concentration of Zn^{2+} ions will increase so choice (C) is not correct. The mass of the zinc electrode will decrease as Zn(s) is oxidized to form $Zn^{2+} + 2e^-$.

The correct answer is (D).

[LO 3.13 SP 5.1]

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41. The oxidation state for chromium changes from +3 in Cr_2O_3, to 0 as the element. It gains electrons, so it undergoes reduction. The oxidation state for carbon changes from +2 in CO to +4 in CO_2. The carbon loses electrons and undergoes oxidation. Cr_2O_3, alternative (A), undergoes reduction while CO, option (B), undergoes oxidation. CO_2, choice (C), is the product formed by the oxidation of CO and Cr, selection (D), is the product of the reduction of Cr_2O_3.

The correct answer is (B).

[LO 3.8 SP 6.1]

42. The ions, Ca^{2+}, K^+ and Cl^- are isoelectronic with the electron configuration: $3s^2\ 3p^6$. The sizes of these species will be inversely related to the number of protons as $Ca^{2+} < K^+ < Cl^-$. The K^o atom has its outer electron in the next energy level, $4s^1$, and thus would be larger than the other three. The order of the four species will be $Ca^{2+} < K^+ < Cl^- < K^o$. The other three choices have one or more substances out of order.

The correct answer is (A).

[LO 1.9 SP 6.4]

43. As a halide, the Br^- ion has a charge of -1. Thus, the Al in $AlBr_3$ is +3. Selenium, Se, is in group 16 and forms ions with a -2 charge. The combination of these two ions requires two Al^{3+} and three Se^{2-} ions to give the formula Al_2Se_3. The formula AlSe, alternative (A), would result if the two ions had the same charges while $AlSe_2$, option (B), would occur only if the charge on Al cation were twice as great as that on the Se anion. $AlSe_3$, choice (C), would result if the charge on the Se anion were the same as that on the Br^- ion.

The correct answer is (D).

[LO 1.11 SP 3.1]

44. In the electromagnetic spectrum, the energies of infrared, visible and ultraviolet light increase in that order. Thus, the stretching of a C–H bond that is caused by infrared radiation would have the lowest energy. The promotion of a *d*-electron that is observed in the visible region would have the next lowest energy. The excitation of an electron in benzene, which occurs in the UV, has the highest energy of the three transitions listed. The order is II < I < III.

The correct answer is (B).

[LO 1.15 SP 4.1]

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45. An intermediate is a substance that is produced in one step of a mechanism and consumed in a later step. NO(g), alternative (A), is formed in the first step but is not consumed in the second step. It appears as a product of the overall reaction. NO_2, option (B), appears as both a reactant and a product. In the overall equation for the reaction the product NO_2 would be subtracted from the two NO_2s in the reactants to give an overall equation of $NO_2(g) + CO(g) \rightarrow CO_2(g) + NO(g)$. NO_3, choice (C), is formed in the first step and consumed in the second. Therefore, NO_3 is an intermediate. CO, selection (D), appears as a reactant in the second elementary step and as a reactant in the overall reaction.

The correct answer is (C).

[LO 4.7 SP 6.5]

46. A catalyst is a substance that provides an alternate pathway with a lower activation energy and, thus, accelerates a chemical reaction. Catalysts may be in the same phase as the reactants, in which case they are referred to as homogeneous or may be in a different phase and are referred to as heterogeneous. Catalysts are often written in the reactants and products. In alternative (A), the Pt(*s*) is a catalyst and, because it represents a different phase than the gaseous reactants, is a heterogeneous catalyst. In option (B), $NO_2(g)$ catalyzes the reaction of $SO_2(g)$ and $O_2(g)$ and is in the same phase so it is a homogeneous catalyst. In choice (C) the hydrolysis of the ester RCOOR′ in aqueous solution is catalyzed by $H^+(aq)$. The $H^+(aq)$ is a homogeneous catalyst. The decomposition of $H_2O_2(aq)$ in selection (D) is catalyzed by $Br^-(aq)$, which serves as a homogeneous catalyst. The only one of these catalysts that is not in the same phase as the reactants is Pt(*s*).

The correct answer is (A).

[LO 4.9 SP 6.2]

47. The order of each reactant can be found by determining how the reaction rate changes with a change in concentration of that reactant while the concentration of the other reactant is held constant. The order of the I^- can be found by comparing its concentration and the rates in the first two trials (when the $[H_2O_2]$ is constant). $[I^-]_2/[I^-]_1 = 0.030/0.020 = 1.5$ while $Rate_2/Rate_1 = 0.0045/0.0030 = 1.5$. Because the concentration and the rate change by the same factor the order for I^- is 1. The order for H_2O_2 can be found by comparing its concentration and the reaction rates in trials one and three (where the $[I^-]$ is held constant). The $[H_2O_2]_3/[H_2O_2]_1 = 0.040/0.030 = 1.33$ while the rate varies as $Rate_3/Rate_1 = 0.0040/0.0030 = 1.33$. These ratios are the same so the order of H_2O_2 is 1. The rate equation is $Rate = k[I^-][H_2O_2]$, alternative (A). The equation in option (B) has each of the concentrations raised to the ratios of the concentrations. In choice (C) the I^- is second order and in selection (D) both I^- and H_2O_2 are second order.

The correct answer is (A).

[LO 4.2 SP 5.1]

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48. The reaction represents the combustion of C(*s*), so ΔH° is negative and one mole of a solid and one mole of a gas form two moles of gas so the sign of ΔS° is positive. This combination of ΔH° and ΔS° makes the sign of ΔG° negative, which is consistent with the fact that this reaction is spontaneous.

The correct answer is (C).

[LO 5.13 SP 2.2]

49. Adding the same mass of Mg(s) to 50 mL of 3.0 M HCl, alternative (A), will increase the rate of the reaction, but will also increase the volume of H_2 formed, because more moles of H^+ are present to react with the excess Mg(s). Adding the same mass of Mg(s) in smaller pieces to HCl with the same volume and concentration will increase the rate of the reaction, because the surface area of the solid will be increased. The volume of H_2 will not increase, because the number of moles of HCl (the limiting reagent) is not increased. If the volume of the 2.0 M HCl is doubled, choice (C), the rate will remain the same but the volume of H_2 will be increased. Increasing the temperature from 25°C to 35°C, selection (D), will increase the rate of the reaction but will also increase the volume the H_2 occupies in accordance with PV = nRT.

The correct answer is (B).

[LO 4.1 SP 4.2]

50. Bond energies represent the energy released when a bond is formed, so the bond energy of the H–Cl bond can be found by using the equation; $\Delta H_{rxn} = BE(\text{reactants}) - BE(\text{products})$. Thus, $-184.6 = Be_{H-H} + BE_{Cl-Cl} - 2\,BE_{H-Cl}$. For the numbers given, $2\,BE_{H-Cl} = 184.6 + 436 + 243$, from which the bond energy of a single H–Cl bond $BE_{H-Cl} = \dfrac{184.6 + 436 + 243}{2}$. Alternative (A) is not correct because it would give a negative bond energy value and would be twice as large as it should be. Option (B) is not correct, because all signs should be (+) when solving for BE_{H-Cl} should be divided by 2. Choice (C) has the signs correct, but should be divided by 2, as in selection (D).

The correct answer is (D).

[LO 5.8 SP 2.3]

51. Both the cooling and the freezing are exothermic changes, and both must occur for the water to freeze. Alternative (A) shows the Joules (not kJ) released by the cooling of the H_2O to 0°C. Option (B) includes the kJ released upon freezing but subtracts this value from the kJ released upon cooling. Choice (C) gives the total number of kJ released for the entire process. Selection (D) includes only the kJ released due to freezing.

The correct answer is (C).

[LO 5.6 SP 2.2, 2.3]

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52. The fundamental principle of calorimetry is that the energy lost by one substance (or produced in a reaction) is equal to the energy gained by another. Although mass is conserved in this process, choice (A), calorimetry is not used to illustrate this principle. The First Law of Thermodynamics, alternative (B), states that energy is neither created nor destroyed, merely transferred, which calorimetry illustrates very well. Hess' Law, selection (C), involves the addition or subtraction of chemical equations and their enthalpies to give the enthalpy of another reaction. This is not illustrated by calorimetry. The Law of Multiple Proportions, option (D), is not illustrated by calorimetry.

The correct answer is (B).

[LO 5.7 SP 4.2)

53. A decrease in the temperature from 400 K to 200 K would cause the curve to shift toward the left with a higher peak. The E_a of the reaction is not affected by temperature so selections (A) and (D) cannot be correct. Choice (B) is not correct because the distribution curve would sharpen with a decrease in T as stated above. Only the distribution curve would move.

The correct answer is (C).

[LO 5.2 SP 1.1, 1.4, 7.1]

54. A process with $\Delta H^\circ > 0$ and $\Delta S^\circ > 0$ will be non-spontaneous at low temperatures, because the ΔH° value will dominate (since $-T\Delta S^\circ$ is small). As the temperature increases, the $-T\Delta S^\circ$ becomes more important and will eventually exceed the $+\Delta H^\circ$ to make the reaction spontaneous. Such a reaction is NOT always spontaneous, choice (A), or never spontaneous, option (B).

The correct answer is (C).

[LO 5.13 SP 2.2]

55. The hydrocarbon tails of detergents such as $H_3C(CH_2)_3C_6H_4CO_2^-Na^+$ are hydrophobic and do not interact with H_2O molecules, choice (C), although the $-CO_2^-$ groups do interact with H_2O. These hydrophobic tails interact with one another, selection (A). The $-CO_2^-$ would not interact readily with one another, alternative (B), but would repel one another due to their similar charges. Although the $-CO_2^-$ groups would interact with Na^+ ions, option (D), this would not cause the clumping that is observed.

The correct answer is (A).

[LO 5.11 SP 7.2]

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56. The pH of a 0.1 *M* solution of $HC_2H_3O_2$ ($K_a = 1.8 \times 10^{-5}$) can be found from $-\log(0.10 \times 1.8 \times 10^{-5})^{1/2}$. This would give a value near 3.00. A pH of 1.00 , alternative (A), would be obtained for a 0.10 *M* solution of a strong acid. A value of 5.00, choice (C), would be obtained for a 0.10 *M* solution of an acid with a K_a of ~ 10^{-9}. A pH = 7.00, selection (D), is the pH for pure H_2O.

The correct answer is (B).

[LO 6.16 SP 2.2]

57. The pH of a 0.10 *M* HCl solution will be 1.0 because HCl ionizes completely and the $[H^+] = 0.10$ *M*, but the pH in a 0.10 *M* solution of $HC_3H_5O_3$, for which $K_a = 1.4 \times 10^{-4}$, will have a pH between 2 and 3. Thus alternative (A) is not correct. The percent dissociation for these two acids, option (B), is not the same. The 0.10 *M* HCl will react more rapidly with Mg metal than will 0.10 *M* $HC_3H_5O_3$, which depends on the concentration of H^+ ions in solution, so choice (C) is not correct. Because the two acid solutions contain the same number of moles of H^+, the volume of 0.050 *M* NaOH needed for neutralization, selection (D), will be the same.

The correct answer is (D).

[LO 6.12 SP 1.4]

58. Alternative (A), 100 mL 0.5 *M* $HC_2H_3O_2(aq)$ + 100 mL 0.5 M $HCl(aq)$. is a mixture of a strong and a weak acid that does not constitute a buffer solution. Option (B), 50 mL 0.5 *M* $HC_2H_3O_2(aq)$ + 50 mL 0.5 *M* $NH_3(aq)$, option (B) would react completely to form a solution of $NH_4C_2H_3O_2$ that is not a buffer solution. In choice (C), 100 mL 0.5 *M* $HC_2H_3O_2(aq)$ + 50 mL 0.5 *M* $NaOH(aq)$, the weak acid would react with the strong base, resulting in equal concentrations of the weak acid and its conjugate base, aka, a buffer. Selection (D), 100 mL 0.5 *M* $HCl(aq)$ + 50 mL 0.5 *M* $NH_3(aq)$, would produce equal concentrations of $HCl(aq)$ and $NH_4Cl(aq)$, which is not a buffer soluion .

The correct answer is (C).

[LO 6.20 SP 6.4]

59. The equilibrium expression for this reaction is $K = [NO_2]^2/[N_2O_4]$. If an initial pressure of 1.00 atm for $N_2O_4(g)$ has an equilibrium pressure of 0.25 atm, 0.75 atm must have been converted to give a pressure for $NO_2(g)$ of 1.50 atm (due to the 1:2 stoichiometry). When these values are substituted into the equilibrium expression $K = (1.5)^2/0.25 = 9.0$, choice (D). The value of 2.3, alternative (A), result from squaring (but not doubling) the pressure of $NO_2(g)$, 0.75 atm. The value of 3.0, option (B), is obtained by neither doubling nor squaring 0.75 atm. A $K = 6.0$ is obtained by doubling 0.75 to give 1.50 (but not squaring it) before dividing by 0.25 atm.

The correct answer is (D).

[LO 6.5 SP 2.2]

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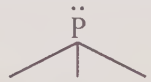
60. The Lewis dot structure for PH_3 is  . The four charge centers around the P will be directed toward the corners of a tetrahedron to minimize their mutual repulsions. The atoms cannot lie in the same plane as they would need to be in order to form a square, alternative (A), or have triangular planar geometry, option (B). The three H atoms would form a triangle below the P atom, giving a triangular pyramid, choice (C), rather than a tetrahedron, selection (D).

The correct answer is (C).

[LO 2.21 SP 1.4]

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CONSTRUCTED-RESPONSE SOLUTIONS

Question 1

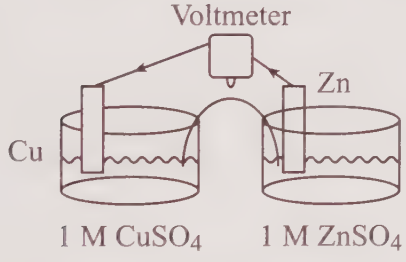
(a) Heat = q = (mass of solution)(ΔT)(specific heat)
q = (127g)(7.5°C)(4.31 $Jg^{-1}°C$) = 4105 = **4100 Joules**
Note: The specific heat is given for the *resulting solution*, not just the $CuSO_4$ solution, and the mass of the *resulting solution* containing the Zn dust imbedded in it as it is swirled/stirred is 125 g + 2.00 g Zn = **127 g**

(b) Moles of Cu^{2+} in solution = 0.125 L × 0.152 mol/L = 0.019 mol $CuSO_4$ = **0.019 mol Cu^{2+} ions**

(c) $$\Delta H = -q = \frac{-4100 \text{ joules}}{\text{moles } Cu^{2+}} \times \frac{1 \text{ kJ}}{0.019 \text{ mole } Cu^{2+} \text{ ions}} = \mathbf{-216 \text{ kJ/mole } Cu^{2+}}$$

(Note: the negative sign on ΔH corresponds correctly with a rising temperature; i.e, an exothermic reaction.)

(d) i.



Wet filter paper between beakers - no funnel needed in diagram

ii. Using the standard reduction potentials given at the beginning of the question.
E°_{cell} = reduction − oxidation voltage = +0.34 v −(−0.76v) = +1.10 v = theoretical E°_{cell}

$$\% \text{ error} = \frac{\text{error}}{\text{Theoretical voltage}} \times 100\% = \frac{1.10 \text{ v} - 1.03\text{e v}}{1.10 \text{ v}} \times 100\%$$

= **6.36% error**

(f) $$\Delta G^\circ = -nFE^\circ = \frac{-2 \text{ moles } e^-}{\text{mole } Cu^{2+}} \times \frac{96{,}500 \text{ Joules}}{\text{volt per mole } e^-} \times 1.03 \text{ volts} = -199{,}000 \text{ J} = \mathbf{-199 \text{ kJ/mole } Cu^{2+}}$$

using the student's value for E°_{cell}. The wording in the question does not rule out using the 1.10 standard cell voltage, but that was not the author's intent. If that value is inserted as E°_{cell}, then the answer for ΔG° becomes −212 kJ/mole Cu^{2+}

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(g) Using the Gibbs Free Energy equation, $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$, we have values for ΔH° and ΔG°, and using the common assumption that ΔH will remain constant over this temperature change. The set-up becomes $\Delta S^\circ = \frac{\Delta H^\circ - \Delta G^\circ}{T}$ which becomes

$\frac{-216\text{ kJ/mol} - (-199\text{ kJ/mole})}{298\text{ K}} = 0.057\text{ kJ mol}^{-1}\text{K}^{-1} = \mathbf{-57\ J\ mol^{-1}K^{-1}}$ or using −212,

$\frac{-216\text{ kJ/mol} - (-212\text{ kJ/mole})}{298\text{ K}} = -0.013\text{ kJ mol}^{-1}\text{K}^{-1} = \mathbf{-13\ J\ mol^{-1}K^{-1}}$

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Question 2

(a)

	$HC_2H_3O_{2(aq)} + H_2O_{(l)} \leftrightarrow H_3O^+_{(aq)} + C_2H_3O_2^-{}_{(aq)}$		
Init	0.10 M	0	0
Change	−x	+x	+x
Eq.	0.10 − x	x	x

$$K_a = [H_3O^+][C_2H_3O_2^-]/[HC_2H_3O_2]$$

$$1.8 \times 10^{-5} = x^2/(0.10 - x)$$

$$x = 1.3 \times 10^{-3}$$

$$pH = 2.89$$

(b) Acetate is a basic anion and causes hydrolysis of the water to form a basic solution:

$$C_2H_3O_2^-(aq) + H_2O(l) \leftrightarrow OH^-(aq) + HC_2H_3O_2(aq)$$

I	0.10 M	0	0
C	−x	+x	+x
E	0.10 − x	x	x

$$K_b = K_w/K_a = 5.6 \times 10^{-10} = \frac{[OH^-][HC_2H_3O_2]}{[C_2H_3O_2^-]}$$

$$= x^2/0.10 - x$$

$$x = 7.6 \times 10^{-6}$$

$$pOH = 5.12$$

$$pH = 14 - pOH = 8.88$$

(c) Since $[H_3O^+] = K_a\,(HC_2H_3O_2/C_2H_3O_2^-) = (1.8 \times 10^{-5})[0.10 - x/0.10 + x]$
Since x is very small, the ratio of acetic acid:acetate is 1:1 and does not affect the $K_a = [H_3O^+]$ relationship. Thus $pH = pK_a = -\log(1.8 \times 10^{-5}) = 4.74$.

(d) The pH would drop with the addition of strong acid, but only slightly. The buffer's base (acetate anions) would absorb the acid to form more acetic acid, which in turn would ionize (but less than 5%) to form more acetate anions again.

(e) There would be no effect on the pH, because the ratio of weak acid to its conjugate base would remain the same; both are diluted to the same extent. There would be no change in pH.

(f) The best choice would include an acid with K_a as close to the target $[H_3O^+]$ as possible, since $pH = pK_a$. Since the target pH of 8.00 means $[H_3O^+]$ is as close to 1.0×10^{-8} as possible, the best choice from the list is hypochlorous acid with $K_a = 3.5 \times 10^{-8}$. The other component of the buffer system would be a salt containing the conjugate base hypochlorite anion, ClO^-. Good choices for the salt might be potassium hypochlorite or sodium hypochlorite.

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Question 3

(a) The oxidation number of the Mn in MnO_4^- is +7, and +2 in the final Mn^{2+} ion. The MnO_4^- must **gain** five electrons to become Mn^{2+}. The process is reduction.

(b) $0.550\text{ g FAS} \times 1\text{ mole FAS}/284.05\text{ g} = 1.936 \times 10^{-3}\text{moles FAS}$

[LO 3.4 SP 2.2, 5.1, 6.4]

(c) Starting with the answer in (b),

$$1.936 \times 10^{-3}\text{moles FAS} \times \frac{1\text{ mols } MnO_4}{5\text{ mols } Fe^{2+}}/0.0224\text{ L} = 0.0173\ M = [MnO_4^-]$$

[LO 1.19 SP 4.2, 5.1] [LO 1.20 SP 4.2, 5.1]

(d) i. Rinsing the buret with H_2O but not with the $KMnO_4$ solution, would dilute the $KMnO_4$ solution, requiring a larger volume to be added.

ii. Overshooting the endpoint would, again, indicate too large a volume was added.

iii. The correct answer is (iii).
If a small amount of solid FAS remained in the weighing boat, there would be fewer moles of FAS in the flask. Fewer moles of FAS present in the flask would require a smaller volume to reach the endpoint of the reaction.

(e) The moles of $X_2C_2O_4$ will equal the moles of oxalate ion. The moles of oxalate ion can be calculated from the volume and molarity of the $KMnO_4$ and the stoichiometry of the reaction.

$$0.03362\text{ L} \times 0.0185\text{ mol/L} = 6.22 \times 10^{-4}\text{mol } MnO_4^- \times \frac{5\ C_2O_4^{2-}}{2} = 1.555 \times 10^{-3}\text{ mol } C_2O_4^{2-}.$$

The molar mass of the unknown $X_2C_2O_4 = 0.2084\text{ g}/1.555 \times 10^{-3}\text{mol} = 134\text{ g/mol}$. Therefore, the identity of the unknown $X_2C_2O_4$ must be $Na_2C_2O_4$.

[LO 3.3 SP 2.2, 5.1]

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Question 4

(a) $(0.1123 \times 10^{-17}\,\text{J/e}) \times (6.02 \times 10^{23}\,\text{e/mol}) \times (\text{kJ}/1000\,\text{J}) = 676\,\text{kJ/mol}$

(b) Each peak corresponds to the removal of an electron from a specific energy level within the atom. Peak I corresponds to $3s^2$; Peak II corresponds to $2p^6$; Peak III = $2s^2$; Peak IV = $1s^2$

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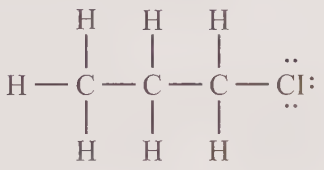
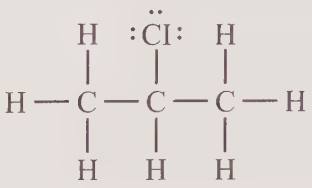
Question 5

(a)

1-chloropropane, $CH_3CH_2CH_2Cl$	2-chloropropane, $CH_3CHClCH_3$
	

(b) Having the chlorine atom at the end of the 1-chloropropane molecule means that it is more polar. The dipole at the end of the chain of 1-chloropropane has more surface area for attraction to a neighboring molecule. Therefore, the dipole-dipole attractive forces between adjacent 1-chloropropane molecules would be greater than those between the 2-chloropropane molecules, leading to a higher normal boiling point.

(c) Yes, mass spectroscopy could be used to distinguish between the two molecules because splitting the molecules apart would give fragments in different proportions. For example, 2-chloropropane has a $-CH_3$ fragment at each end of the molecule while the 1-chloropropane molecule has $-CH_3$ at just one end, so the former might be expected to give twice as many $-CH_3$ fragments with mass 15 as the latter molecule.

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Question 6

(a) The dissociation equation for the strontium sulfate salt in water would be
$SrSO_4(s) \longleftrightarrow Sr^{2+}(aq) + SO_4^{2-}(aq)$.

(b) The solubility product constant expression for the salt strontium sulfate would be
$K_{sp} = [Sr^{2+}][SO_4^{2-}]$.

(c) The net ionic equation (NIE) for the equation describing the reaction between solutions of strontium hydroxide and sulfuric acid would be
$Sr^{2+}(aq) + 2\,OH^-(aq) + 2\,H^+(aq) + SO_4^{2-}(aq) \rightarrow 2\,H_2O(l) + SrSO_4(s)$

(d) The salt strontium sulfate would be less soluble in the acidic sulfuric acid solution, than in pure water. The presence of the common sulfate ion would hinder the solubility. In considering this situation, using Le Chatelier's Principle, one would say that increasing the concentration of the sulfate anion would cause a shift to the left, and less of the salt would dissociate.

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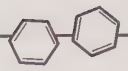

Question 7

(a) The most linear relationship is in graph C, where volume is graphed as a function of time. When the graph of 1/volume is linear, the reactant is second order; when the graph of ln volume as a function of time is linear, the reactant is first order, and when the graph of volume as a function of time is linear, the reactant is zero order. Therefore, the water flow through a buret is zero order. (Note: the molar concentration term or pressure units could also be used). If one collects the data, it takes approximately twice as long to deliver 10 mL of water as it does 5 mL, this means that rate = 10 mL/2 × time = same value as 5 mL/ second. The rate is determined by the diameter of the tip, not on how much is delivered, if one stays in the top half of the buret.

(b) The rate law here takes the form, rate = $k[H_2O]^0$, which is the same format as the formula for a straight line: $y = mx + b$, where **m is the slope** of the straight line. Therefore, if the slope is determined, the values of the slope will be the value for "k," the rate constant.

(c) Yes, a different rate would be observed, because syrup and molasses are thicker, more viscous fluids, so the same volume will not be delivered per second or per minute as with water in the buret.

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SEMESTER 1 EXAMINATION

1. The first step is to identify the limiting reactant. For 10 mol of NH_3, if it is the limiting reactant, with a 1:1 ratio between NH_3 and NO (4:4), 10 moles of NO could form. But with 10 mole of O_2 and a 4:5 mole ratio, $10 \times 4/5 = 8$ mol of NO is formed.

   The correct answer is (B).

   [LO 3.4 SP 2.2]

2. The first issue is to determine the limiting reagent. This can be achieved in a couple of different ways. One way is to find the number of moles of H_2O that could be formed in each case.

   $$1.6 \text{ g } O_2 \times \frac{1 \text{ mole } O_2}{32 \text{ grams } O_2} \times \frac{6 \text{ mole } H_2O}{5 \text{ moles } O_2} = 0.06 \text{ mole } H_2O$$

   $$3.4 \text{ g } NH_3 \times \frac{1 \text{ mole } NH_3}{17 \text{ g } NH_3} \times \frac{6 \text{ mole } H_2O}{4 \text{ mole } NH_3} = 0.30 \text{ mole } H_2O$$

   The second way is to find the mass of O_2 needed to react with 0.2 moles of initial reactant NH_3:

   $3.4\text{g } NH_3 \times \frac{1 \text{ mole}}{17\text{g}} = 0.20 \text{ moles } O_2 \times 32 \text{ g/mole} = 8.0 \text{ g}$. Since only 0.16 g O_2 is available, O_2 is the limiting reactant.

   The correct answer is (C).

   [LO 3.4 SP 2.2]

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3. The number of atoms in the reactants and products is unchanged but the number of moles is not conserved so option (A) cannot be correct. The number of molecules is not conserved from the reactants to the products so choice (B) is not correct. As in option (A) the number of moles is not conserved so selection (C) is not correct. The number of atoms and the mass are conserved so (D) is a correct statement.

   The correct answer is (D).

   [LO 1.18 SP 1.4]

4. The weaker the attraction is, the lower the ionization energy is. Element II, choice (B) has a lower first IE than any of the other elements listed so element II must have the weakest attraction for the electron.

   The correct answer is (B).

   [LO 1.5 SP 1.5, 6.2]

5. In order to form a 3+ ion the first three IEs and their total must be low. Element IV exhibits relatively low first, second and third ionization energies which would lead to the formation of a 3+ cation.

   The correct answer is (D).

   [LO 1.5 SP 1.5, 6.2]

6. Since element IV shows a significant jump from IE_3 to IE_4, its fourth electron must be in the next, lower energy level leaving three in the valence subshells, to give an electron configuration of $ns^2\ np^1$.

   The correct answer is (B).

   [LO 1.7 SP 5.1, 6.2]

7. All of the elements are in the third period with electronic configurations from $[1s^2\ 2s^2]$ to $[1s^2\ 2s^2\ 2p^5]$ Mg $3s^2$ (no unpaired electrons), Al $3s^2\ 3p^1$ (1 unpaired electron), P $3s^2\ 3p^3$ (3 unpaired electrons), Cl $3s^2\ 3p^5$ (1 unpaired electron). P has the largest number of unpaired *p* electrons.

   The correct answer is (C).

   [LO 1.9 SP 6.4]

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8. Referring to the electron configurations in q. 7, the only element with all of its valence electrons in a single subshell is Mg ($3s^2$).

   The correct answer is (A).

   [LO 1.9 SP 6.4]

9. Of the elements listed the only one that forms a stable diatomic molecule is Cl.

   The correct answer is (D).

   [LO 1.9 SP 6.4]

10. Diamond is one of several forms of carbon. It is a covalent network solid in which all the atoms are connected by single bonds.

    The correct answer is (B).

    [LO 2.22 SP 4.2]

11. Magnesium oxide is formed from a metal and a nonmetal with very different electronegativities. Electrons are transferred from the magnesium atom (forming a magnesium ion) to an oxygen atom (forming an oxide ion). These ions combine in a repeating lattice to form an ionic solid.

    The correct answer is (C).

    [LO 2.22 SP 4.2]

12. Graphene is one of several forms of carbon. It consists of a single layer of carbon atoms bonded to one another by covalent bonds. These atoms are arranged in six-member rings in a covalent network solid.

    The correct answer is (B).

    [LO 2.22 SP 4.2]

13. Carbon dioxide consists of individual molecules in which the atoms are held together by covalent bonds. Because the molecules are not polar the only forces holding them to one another are London forces.

    The correct answer is (A).

    [LO 2.22 SP 4.2]

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14. From II to III, the substance is undergoing condensation as gaseous molecules are converted to liquid. This process occurs with the formation of intermolecular attractions formed between X_2 molecules.

The correct answer is (B).

[LO 2.3 SP 6.4, 7.1]

15. Between points III and IV only liquid is present, which means that options (C) and (D) cannot be correct. There is no change in the bonding until point IV where the solid begins to form so choice (B) is not correct. The decrease in temperature reflects a decrease in the average molecular motion.

The correct answer is (A).

[LO 2.4 SP 6.4, 7.1]

16. The number of particles can be determined by dividing the mass by the atomic mass for each of the choices except (A), where the molar mass must be used because F_2 is diatomic. The number of F_2 molecules is (10.0/38) × Avogadro's Number. No. while the number of Ne atoms is (10.0/20) × Av. No. The number of Na atoms is (10.0/23.0) × Av. No. and the number Ar atoms is (10.0/39.5) × Av. No.

The correct answer is (B).

[LO 1.4 SP 7.1]

17. Column chromatography, option (A), could be used to separate these dyes but is likely to take much more time than paper chromatography, choice (D). Distillation, selection (B), is best suited to substances that can be converted to vapor, then condensed while filtration, alternative (C), works best for mixtures in which one substance is insoluble.

The correct answer is (D).

[LO 2.10 SP 4.2]

18. All four acids involve the separation of H^+ ions from anions of increasing size ($F^- < Cl^- < Br^- < I^-$). According to Coulomb's Law the energy required to separate the ions decreases as the distance between them increases. HF, alternative (A), would be most difficult to separate and therefore would be the weakest. The other choices (HCl, HBr, and HI) are all strong acids.

The correct answer is (A).

[LO 2.14 SP 1.4]

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19. The number of moles of H^+ ions can be obtained by multiplying the volume (in L) by the molarity, including the number of H^+ per mole of acid if needed. Option (A) yields 0.0010 moles of H^+ ions. Alternative (B) gives 0.0016 moles of H^+ ions. while choices (C) and (D) would give 0.0050 mol and and 0.010 mol, respectively.

The correct answer is (B).

[LO 1.20 SP 4.2]

20. When a metallic oxide dissolves in H_2O, the oxide ion reacts with H_2O molecules to form OH^- ions, not oxygen gas as suggested in alternative (A), or H^+ ions, choice (B), and the metal does not precipitate as stated in selection (C).

The correct answer is (D).

[LO 3.2 SP 1.5]

21. The molecule NH_3 does not tend to donate a proton as would be necessary for a Bronsted-Lowry acid, alternative (A). It will gain a proton, the definition of a Bronsted-Lowry base, option (B). It will not react with an OH^- ion, as would be required for an Arrhenius acid, selection (C), and lacks an OH^- to donate as would be expected for an Arrhenius base, choice (D).

The correct answer is (B).

[LO 3.7 SP 6.1]

22. Zn and S react in a 1:1 mole ratio. Doubling the quantity of Zn without doubling the quantity of S will not increase the mass of ZnS formed, alternative (A), or form a different compound such as Zn_2S, selection (B). It will form 0.97 g of ZnS with 0.65 g of Zn remaining, choice (C). The extra Zn will not sublime, as suggested in option (D).

The correct answer is (C).

[LO 3.5 SP 2.1]

23. If the test tube feels warm to the touch the dissolving process releases heat. This means that the process is exothermic rather than endothermic, which would absorb heat and make the test tube feel cold. Thus, options (A) and (B) cannot be correct. Exothermic processes have $\Delta H < 0$ so choice (C) cannot be correct.

The correct answer is (D).

[LO 3.11 SP 1.5]

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24. Ionic compounds are brittle, alternative (A), have high melting points, choice (C), and have low volatility, option (D). They do not conduct electricity in the solid, selection (B), although they do conduct electricity when molten.

The correct answer is (B).

[LO 2.19 SP 1.1]

25. The kinetic molecular theory of gases states that gases are mostly empty space, alternative (A). It also states that collisions between gas molecules are elastic, selection (B), and that those molecules are in constant, chaotic motion, choice (C). It makes no statement about gases having zero volume at absolute zero, option (D), although that is true.

The correct answer is (D).

[LO 2.4 SP 1.4]

26. Nitrogen and fluorine are both nonmetals with relatively high electronegativities. Electrons will not be transferred with the formation of ionic bonds, choice (A), nor will electrons be released to move freely as in metallic bonding, option (B). They will share electrons in their bonds forming covalent bonds. Those bonds will be polar, selection (D), rather than nonpolar, alternative (C), due to the difference in their electronegativities.

The correct answer is (D).

[LO 2.17 SP 6.4]

27. The balanced equation is

$$P_2O_5 + 3\,Ba(OH)_2 \rightarrow Ba_3(PO_4)_2 + 3\,H_2O$$

The sum of the coefficients is 8.

The correct answer is (B).

[LO 3.2 SP 1.5]

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28. Carbon dioxide dissolves in H_2O to form the weak acid H_2CO_3. The ionization of this acid produces sufficient H^+ ions to lower the pH from 7.0 to 5.7, alternative (A). There is not enough nitrogen monoxide (NO) in the atmosphere to saturate the H_2O, option (B), and even if there were it would have no effect on the pH of the H_2O. Distillation removes acidic as well as basic impurities from the H_2O, choice (C), resulting in a pH of 7.0. The H_2O undergoes self-ionization, selection (D), but when it does, H^+ and OH^- ions are produced in equal quantities resulting in a pH of 7.0, not 5.7.

The correct answer is (A).

[LO 3.7 SP 6.1]

29. The ratio of the mass of sodium to the mass of the compound is the greatest for Na_2O, choice (C), where the ratio is 46.0/62. The ratios for the other options are 23.0/42.0, alternative (A), 23.0/58.5, option (B) and 46/78, selection (D).

The correct answer is (C).

[LO 1.2 SP 2.2]

30. Oxidation-reduction reactions can be identified by a transfer of electrons or by a change in oxidation numbers. In alternative (A), H_2O_2, in which the Os have an oxidation number of -1, decomposes to form H_2O (O oxidation number $= -2$) and O_2 (oxidation number $= 0$). In option (B) an H^+ ion is transferred from HCl to NH_3, forming the NH_4^+ ion in solid NH_4Cl in an acid-base reaction. Choice (C) is also an acid-base reaction in which SO_3 reacts with H_2O to form H^+ and HSO_4^-. Selection (D) represents a change of state, the sublimation of solid I_2 to form gaseous I_2.

The correct answer is (A).

[LO 3.8 SP 6.1]

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CONSTRUCTED-RESPONSE SOLUTIONS

Question 1

(a) The balanced net ionic equation to describe the reaction might be written in two different ways:
$Zn(s) + 2\,H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$
OR
$Zn(s) + 2\,H_3O^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g) + 2\,H_2O(l)$

(b) i. To calculate the mass of zinc in the brass alloy, start with the mass of zinc(II) chloride residue:
$0.195\text{ g } ZnCl_2 \times (1\text{ mol } ZnCl_2/136.28\text{ g } ZnCl_2) \times (1\text{ mol Zn}/1\text{ mol } ZnCl_2)$
$\times (65.38\text{ g Zn}/1\text{ mol Zn}) = 0.0936\text{ g Zn}$

ii. Find the mass of copper in the brass alloy by subtracting the mass of zinc from the total mass:
$1.00\text{ g alloy} - 0.0936\text{ g Zn} = 0.906\text{ g Cu}$

iii. To find the volume of hydrogen gas, first find the number of moles of hydrogen gas, then use the Ideal Gas Law to calculate the volume:
$0.0936\text{ g Zn} \times (1\text{ mol Zn}/65.38\text{g Zn}) \times (1\text{ mol } H_2/1\text{ mol Zn}) = 0.00143\text{ mol } H_2$
$V = (nRT)/P = (0.00143\text{ mol } H_2 \times 62.37\text{ L torr/mol K} \times 296\text{ K})/(751\text{ torr})$
$= 0.0351\text{ L} = 35.1\text{ mL}$

iv. To find the mass percent of each element in the alloy, compare each element's mass to the total mass of the alloy and convert to percent:
$(0.906\text{ g Cu}/1.00\text{ g alloy}) \times 100\% = 90.6\%\text{ Cu}$
$(0.0936\text{ g Zn}/1.00\text{ g alloy}) \times 100\% = 9.36\%\text{ Zn}$

v. Dissolve a known mass of alloy in excess concentrated nitric acid to change the copper in the alloy into Cu^{2+} cations, which are blue in solution. Dilute the solution to a known volume. Then use a spectrophotometer to compare the amount of absorbance of orange light through the sample to the absorbance of a known sample of Cu^{2+}. Since Beer's Law states that absorbance and concentration of the colored solution are proportional, the concentration of Cu^{2+}, the number of moles of copper, and its mass can all be calculated by simple stoichiometry. This mass of copper would then be compared to the original mass of alloy to determine a mass percent of copper.

[LO 1.2 SP 2.2] [LO 1.4 SP 7.1]

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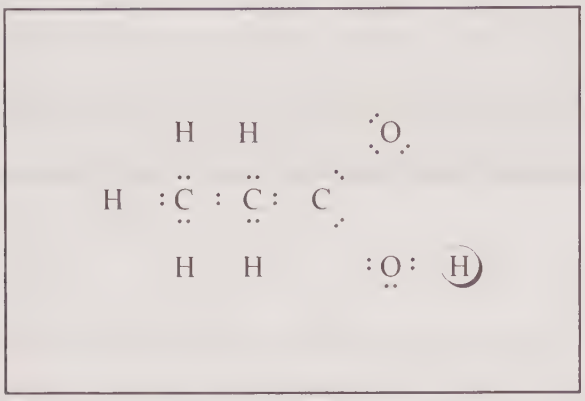
Question 2

(a) i.



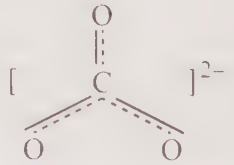
ii. 1. sigma <u>10</u> pi <u>1</u>

Sigma bonds are formed when the first pair of electrons in a bond are formed. There are six sigma bonds with hydrogen, two sigma bonds between carbon atoms, and two sigma bonds between carbon and oxygen. Pi bonds refer to subsequent bonds formed between two atoms after the sigma (initial) shared pair forms a covalent bond. There is a double bond formed between carbon and one of the oxygen atoms; the first shared pair result in a sigma bond, the second shared pair in the double bond is the pi bond.

2. No, the bond between the carbon and oxygen with a hydrogen (C–O–H) is a single bond, but the bond between carbon and oxygen alone (C = O) is a double bond. With greater electron density in the double bond, this bond will require more energy to initiate the bond-breaking.

(b) i. CO_2 <u>linear</u> CO_3^{2-} <u>triangular</u>

ii. The bonding structure in CO_2 is O=C=O, with two double bonds. Because the bonds are equivalent, the bond order in either bond is two, resulting from the 2 shared pairs of electrons in each C–O bond. In the carbonate, CO_3^{2-}, ion, we have an equilateral triangular shape with 3 sigma bonds between the carbon atom and the three oxygen atoms and an additional pair of electrons (note the 2− charge on the ion) that becomes delocalized over all three bonds. This is now a resonance structure with the electron density between each carbon and oxygen atom equivalent to 1 1/3 or 1.33 bonds. The bond order is 4/3 or 1.3. Fractional bond orders are indicative of a resonance structure. The additional fractional bond is frequently depicted with a dotted line as in the figure below.



[LO 2.17 SP 6.4]

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Question 3

(a) i. $N_2 \rightarrow H_3N$

Nitrogen is going from neutral (zero) to -3 oxidation number, and to become negative, a gain of electrons must take place. Reduction is defined as the gain of electrons. The skeletal equation is **reduction**.

ii. $H^+(aq) \rightarrow H_2O(l)$

Hydrogen begins with an oxidation number of +1 and each hydrogen in water is also +1 oxidation number. Therefore, no change in oxidation state has taken place. The partial reaction is **NEITHER** oxidation nor reduction.

iii. $Al^{3+} \rightarrow Al$

For aluminum to go from a +3 oxidation number as an ion to neutral (zero), a gain of electrons must occur. The gain of electrons is associated with **reduction**.

[LO 3.8 SP 6.1]

(b) i. $3\,H_2 + N_2 \rightarrow 2\,NH_3$

[LO 1.18 SP 1.4]

ii. $$44.0\text{ g } N_2 \times \frac{1\text{ mol } N_2}{28.02\text{ g } H_2} \times \frac{2\text{ mol } NH_3}{1\text{ mol } N_2} \times \frac{17.04\text{ g } NH_3}{1\text{ mol } NH_3} = 53.4\text{ g } NH_3$$

$$44.0\text{ g } H_2 \times \frac{1\text{ mol } H_2}{2.02\text{ g } H_2} \times \frac{2\text{ mol } NH_3}{3\text{ mol } H_2} \times \frac{17.04\text{ g } NH_3}{1\text{ mol } NH_3} = 248\text{ g } NH_3$$

The limiting reactant is the nitrogen, which has a higher molar mass, leading to a lower number of available moles N_2 (compared to H_2) to start with. **53.4 g** is the maximum mass of NH_3 that can form.

iii. If the student obtains a value of 48.72 g for the mass of NH_3 formed, what is the per cent error in this process?

$$\%\text{error} = \text{error} \times 100\% = \frac{53.4\text{ g} - 48.72\text{ g}}{53.4\text{ g}} \times 100\% = 4.68/53.4 \times 100 = \mathbf{8.76\%}$$

[LO 1.4 SP 7.1]

iv. 1. At constant temperature, the volume ratio will be the same as the mole ratio for a gaseous reaction.

$$0.6\text{L } H_2 \times \frac{2\text{ L } NH_3}{3\text{ L } H_2} = 0.4\text{ L } NH_3$$ which could possibly form with the available H_2.

$$0.6\text{L } N_2 \times \frac{2\text{ L } NH_3}{1\text{ L } N_2} = 1.2\text{ L } NH_3$$ which could possibly form with the available N_2.

Hydrogen is therefore the limiting reactant.

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(a) Forming 0.40 L of NH_3 will consume all of the H_2 and and 0.2 L of N_2, leaving 0.4 L of unreacted N_2. Therefore the final volume will be a total of 0.8 L, assuming a flexible container, like a piston or a balloon.
The starting volumes were 0.6 L + 0.6 L = 1.2 L. Therefore the product volume and remaining N_2 is a smaller volume that the original volume (0.6 L + 0.6 L = 1.2 L).

[LO 1.4 SP 7.1]

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Question 4

(a) $SrCl_2(aq) + Na_2SO_4(aq) \rightarrow 2NaCl(aq) + SrSO_4(s)$
$Na^+(aq)$ ions are typically soluble in concentrations of 0.1 *M* or less, so "ppt(1)" cannot be the NaCl; therefore the $SrSO_4$ must be the precipitate.

(b) The complete ionic equation is
$Al^{3+}(aq) + 3\,Cl^-(aq) + 3\,K^+(aq) + 3\,OH^-(aq) \rightarrow Al(OH)_3(s) + 3\,K^+(aq) + 3\,Cl^-(aq)$. K^+ ions are soluble at concentrations of 0.1 *M* or less, so KCl is not the precipitate; it must be $Al(OH)_3$.
When the spectator ions are removed from both sides of the equation, the net ionic equation which remains becomes
$Al^{3+}(aq) + 3\,OH^-(aq) \rightarrow Al(OH)_3(s)$

[LO 3.2 SP 1.5, 7.1]

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Question 5

(a) Light with a wavelength of 58.4 nm is used to eject the electron responsible for Peak I. Calculate the frequency of this light.

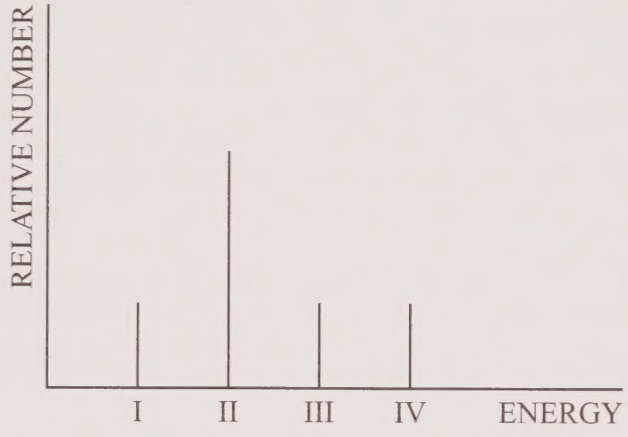
Frequency = c/λ

$$\text{Frequency} = \frac{3.00 \times 10^8 \text{m/ sec} \times 10^9 \text{nm/1m}}{58.4 \text{ nm}} = 5.14 \times 10^{15} \text{ sec}^{-1}$$

(b) Each peak corresponds to the removal of an electron from a specific energy level within the atom. The peak which involves the lowest energy (Peak I) corresponds to the electrons most easily removed- the $3s^2$.

Peak I corresponds to $3s^2$, Peak II corresponds to $2p^6$; Peak III = $2s^2$; Peak IV = $1s^2$.

The height of Peak II should be three times higher than peak I, representing 6 electrons of $2p^6$ compared to two electrons of $3s^2$.



[LO 1.5 SP 1.5, 6.2] [LO 1.6 SP 5.1] [LO 1.7 SP 5.1, 6.2]

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